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MOTTLE-LEAF OF CITRUS TREES IN RELATION TO SOIL CONDITIONS

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INTRODUCTION

"Mottle-leaf" is a term applied in California to a mottled or spotted condition of the leaves of Citrus trees (Pl. XCVI). The affected portions of the leaf appear to be nearly or quite devoid of chlorophyll and are light yellow in color. In the first stages of the disease irregular spots several millimeters in diameter appear between the larger veins, usually midway between the midrib and the margin. The half of the leaf next to the tip is often first affected. In the more advanced stages, the spots are larger and more numerous, until finally the only chlorophyll remaining is confined to the midrib and the larger veins. The various stages are illustrated in Plate H. The condition is distinguished from what is generally termed "chlorosis" by the fact that the areas surrounding the yellowish spots retain their normal green color, at least until the spots embrace a large proportion of the leaf. The term "mottle-leaf" as here used is also to be understood as not including that type of functional disturbance sometimes found in Citrus leaves in which the midrib and veins are lighter in color than the surrounding tissue.

Mottle-leaf in its advanced stages is accompanied by a serious reduction in the yield and in the size and quality of the fruit. The foliage becomes thin and weak, with many very small leaves (Pl. XCVII); and the ends of the branches have a brushy appearance, owing to the development of numerous small weak twigs.

DISTRIBUTION OF MOTTLE-LEAF

Mottle-leaf is at present quite widely distributed through the Citrus areas of California, but is, as a whole, worse in the southern sections of the

[1] The writers are indebted to the University of California Citrus Experiment Station and Graduate School of Tropical Agriculture at Riverside for many courtesies and facilities extended during the course of this work, and to Dr. H. L. Shantz and Mr. R. L. Piemeisel, of the Office of Alkali and Drought Resistant Plant Investigations, for their cooperation in the work preliminary to this investigation.

The writers also wish to express their obligation to the Citrus growers of the sections studied for their cooperation in supplying information regarding the field treatments of their groves and assistance in other ways.

State. It is not a new trouble in California, having been observed by some of the growers at least 15 years ago. During the last three or four years the mottling has become much more pronounced in the groves first affected. Other groves which are reported to have been relatively free from the trouble a few years ago are now badly mottled. There are many groves in the affected districts, however, that show little or no mottling at present.

FACTORS SUGGESTED AS CAUSAL AGENTS IN MOTTLING

The cause of mottling is a much disputed point. Various factors have been assigned as causal agents, such as an excess of lime, magnesium, or organic matter; a deficiency of lime, iron, or organic matter; frost; poor drainage, etc. Smith and Smith [1] conclude from their observations that the most prevalent and typical form of mottle-leaf is due to an irregular supply of moisture and plant food. No fungus or bacterium has yet been proved to be causally associated with mottle-leaf. Thomas,[2] however, has shown that the Citrus-root nematode (*Tylenchulus semipenetrans* Cobb) is widely distributed in districts in which mottle-leaf occurs, but is not invariably found on the roots of affected trees, and the extent to which mottling can be directly induced by such parasitism has not yet been determined.

One of the most striking features of mottle-leaf is the fact that the deficiency in chlorophyll is first in evidence in those portions of the leaf farthest removed from the midrib and largest veins; in other words, farthest from the main conducting channels of the leaf (Pl. H). This suggests a deficiency in the available supply of some substance essential in the formation of chlorophyll. The entire supply of this substance is apparently used by those portions of the leaf near the conducting channels, the supply being insufficient to reach the more remote portions of the leaf. That the disappearance of the chlorophyll is due to the absence of some essential constituent in the leaf rather than to the presence of some deleterious substance is also indicated by the fact that the chlorophyll next to the midrib and larger veins is the last to disappear. If the plant were absorbing something which reacted unfavorably on the chlorophyll, the effect of such absorption might be expected to be first in evidence nearest the veins. This analysis of the problem is to be considered simply as a working hypothesis which up to the present appears to accord with the observations.

The marked reduction in the yield of marketable fruit from badly mottled trees and the decrease in vigor led to the undertaking of a systematic survey of a number of groves in districts in which mottle-leaf

[1] Smith, R. E., and Smith, Elizabeth H. California plant diseases. Cal. Agr. Exp. Sta., Bul. 218, p. 1139. 1911.

[2] Thomas, E. E. A preliminary report of a nematode observed on citrus roots and its possible relation with the mottled appearance of citrus trees. Cal. Agr. Exp. Sta., Cir. 85, 14 p., 8 fig. 1913.

occurs with a view to determining the extent of its correlation with soil conditions. The results of these investigations form the subject of this paper.

FIELD SURVEY

As a basis for the investigation a field survey was made of about 175 orange and lemon groves near Riverside, Redlands, Highland, and Rialto, Cal.; a few groves were also examined in the Ontario, Pomona, and Azusa districts.

Ten or twelve representative trees were selected from each grove examined, usually a 10-acre block. The percentage of mottled leaves on each tree was determined by two men working independently. Soil samples were also taken near the same trees in 1-foot sections to a depth of 3 feet, the samples for a given foot section being combined. The fertilizer treatment of each grove and the cultivation and irrigation methods employed were also ascertained as accurately as the records of each grower would permit.

The soil samples representing each grove were promptly air-dried, and the organic carbon, "humus," total nitrogen, mineral carbonates, and bicarbonates determined in each sample. The moisture equivalent of each sample was also determined in order to compare the moisture retentiveness of the soils.

The limiting of the sampling to a depth of 3 feet was based upon the results of numerous observations, which showed that the feeding roots of orange and lemon trees do not as a rule extend much beyond this depth. The taproots, of course, go deeper when the soil conditions permit; but the feeding root system spreads out laterally near the surface, and this lateral feeding system does not ordinarily fully occupy the ground even to a depth of 3 feet. Excavations in the districts examined showed repeatedly that the main feeding root system was found usually from within a few inches of the surface to a depth of 18 to 24 inches.[1] Soil-moisture determinations in orange groves, to be presented in another paper, also showed that when the upper 3-foot layer dried out below the wilting coefficient, the tree could not get enough water to keep from wilting, even with available moisture immediately below this layer.

EXTRANEOUS FACTORS COMPLICATING THE CORRELATION OF MOTTLING WITH SOIL CONDITIONS

The study of the correlation between the degree of mottling and the general soil conditions of the groves is complicated by a number of extraneous factors. One of these is the kind of stock on which the selected buds are grafted. Other conditions being the same, a tree top on sour-orange stock is likely to show more mottling than one on sweet-

[1] Striking exceptions are, however, occasionally met with. Dr. H. J. Webber, Director of the University of California Citrus Experiment Station, informs the writers that in the Claremont section he has observed fine fibrous roots at a depth of 14 feet.

orange stock. In some instances also, tops on grapefruit stock were found to be more mottled than tops on sweet-orange seedlings. One specific instance of two adjoining navel-orange groves under the same ownership illustrates the case. One grove is on lemon stock, the other on sweet-orange stock. The trees on lemon stock showed 70 per cent of their leaves mottled, and those on the sweet-orange stock 50 per cent. Also, instances were found where individual orange trees on lemon stock were much more mottled than the surrounding trees on sweet-orange stock. As it is frequently impossible to obtain definite information about the stock used, this factor complicates the investigation. The physiological behavior of the buds on various stocks would be an interesting study in this connection.

Frosts and severe winds tend to increase mottling. After a strong, dry, north wind late in the fall of 1912 the leaves on the north side of the trees were more mottled than those on the opposite side. The new leaves put out later on the north side of the tree, however, were less mottled; and during the summer of 1914, the period covered by the field survey, the leaves on the south side of the trees were generally more mottled than those on the north side. Even in very severe cases of mottling, large healthy leaves are also often found in the center of the trees. This suggests that strong sunlight may increase mottling; and if so, the effectiveness of this agency would vary with the size of the trees and the closeness of planting.

Badly mottled trees cut back and rebudded on the stumps produce badly mottled new top growth, and the mottling persists unless the soil treatment is changed.

FERTILIZERS IN RELATION TO MOTTLING

The results of the field survey showed that groves which were plentifully supplied with organic material, either in the form of manures or green cover crops, were less mottled than those that had been fertilized entirely with commercial fertilizers. Several growers stated that they had cured mottle-leaf in limited areas by a liberal application of barnyard manure. It was also found in the case of all the groves included in this field study that each grove that had been fertilized with commercial fertilizers alone and kept under clean cultivation was badly mottled. This condition was especially marked in groves in which sodium nitrate had been employed for a number of years as the principal or only fertilizer. On the other hand, some groves that had received organic fertilizer were also badly mottled. This latter fact has discouraged many growers from using such material, especially manures, which usually have to be purchased and shipped in at high cost.

It was also observed that plowsole (an incipient hardpan just below the cultivated layer) frequently accompanied a badly mottled condition of the tree. Numerous observations have shown that the plowsole is a serious

obstacle in irrigation and gives rise to a droughty condition in the areas affected. The association of mottling with an inadequate soil-moisture supply appears in some instances to be clearly indicated. The relationship, so far as plowsole is concerned, is, however, complicated by the fact that plowsole is often, though not necessarily, associated with a low humus content.

RELATION OF MOTTLING TO YIELD

Badly mottled trees produce smaller fruits and a smaller number of fruits per tree than trees not mottled, and severely mottled branches produce less fruit buds. A slight mottling of the leaves does not appear to have any serious effect on the yield of fruit. The results of the field observations indicate that if less than 20 per cent of the leaves show mottling, the yield is not measurably decreased. The yields of oranges and lemons in the groves studied were obtained in most cases as far back as 1907, but the freezes of 1912 and 1913 proved such a disturbing factor both as regards yield and tree condition that it was not found possible to establish any relation between the yield and the mottling as determined in 1914.

SUSCEPTIBILITY OF DIFFERENT CITRUS TREES TO LEAF MOTTLING

Mixed groves of lemons and oranges were not found in the field survey, so that the relative mottling of the two species under the same cultural conditions could not be directly determined. From indirect comparison there appears to be no great difference in this respect. Grapefruit and tangerine mottle readily, but no opportunity was presented for a direct comparison with lemon or orange trees. There are few tangerines produced in the areas studied.

There seemed to be no difference between the Washington Navel and the Thompson Improved Navel so far as susceptibility to mottling was concerned. Where differences in mottling were found, it was also found that the two varieties were on different stocks. One mixed grove of Washington Navels and Valencias was studied, in which the two varieties were alternated in the same row, so that the conditions were the same for each. In this case both varieties were equally mottled.

RESULTS OF THE SOIL ANALYSES

METHODS OF SOIL ANALYSIS EMPLOYED

The total carbon was determined by boiling 20 gm. of soil with 50 or 75 c. c. of a mixture of sulphuric acid and potassium bichromate, using the larger amount with soils containing more than the average amount of organic matter. The acid mixture was made up in the proportion of 120 gm. of the bichromate to 1,000 c. c. of concentrated sulphuric acid. The carbon dioxid was absorbed in $N/5$ sodium hydrate in a bead tower and the whole of the hydrate solution removed and titrated.

The inorganic carbon (from mineral carbonates) was determined by boiling 20 gm. of soil with 50 c. c. of normal phosphoric acid under a partial vacuum of about 68 cm. of mercury, absorbing the carbon dioxid in $N\frac{2}{3}$ sodium hydrate and titrating as in the case of total carbon. The phosphoric acid liberates the carbon dioxid in mineral carbonates or bicarbonates, but does not appear to attack appreciably the organic matter.

The humus was determined by removing the calcium from 10 gm. of soil with dilute hydrochloric acid (1 per cent), washing out the chlorids, extracting the soil with 500 c. c. of 4 per cent ammonia for 24 hours, and measuring the intensity of the humus color in a colorimeter against a standard humus solution.

The percentage of soluble bicarbonates was determined by shaking the soil with distilled water and allowing it to stand overnight. The clear supernatant liquid was pipetted off the following morning into a Jena flask, a few drops of phenolphthalein added, the flask covered with a watch glass and the solution boiled on a hot plate; while boiling, the red color was titrated out with $N/10$ hydrochloric acid.

The total nitrogen was determined by the modified Kjeldahl method, which includes the nitrogen of nitrates.

ORANGE SOILS

The difficulties encountered in correlating tree growth with soil conditions as determined by a laboratory examination are generally recognized. The soil environment of a tree is by no means uniform, and a soil sample at best represents only the average soil condition, and wholly disregards the local variations in root distribution. In the present investigation the correlation between mottling and soil composition is further complicated by the fact that an orange or lemon tree is, generally speaking, slow in response to fertilizer stimuli under the method of orchard management prevailing in the area studied. An application of barnyard manure, for example, even when thoroughly worked into the soil, does not cause tree response until some time after the manure has decomposed. Under such circumstances a soil sample may not represent the soil conditions responsible for the condition of the trees at the time of sampling

TABLE I.—*Analyses of orange-grove soils in California to a depth of 3 feet*

No.	Percentage of—					Ratio of—				Moisture equivalent.	Trees.			
	Humus.	Total nitrogen.	Organic carbon.	Carbonates.	Bicarbonates.	Humus to lime.	Carbon to humus.	Nitrogen to humus.	Nitrogen to carbon.		Age.	Percentage of mottled leaves.	Variety.	Location.
											Years.			
1	0.033	0	0.271	0.051	0.023	0.66	8.15	0	0	10.4	21	89	Valencia	A. H. 74–2.
2	.033	.034	.267	.051	.023	.66	8.00	1.01	.13	10.4	21	73	do	A. H. 74–3.
3	.041	.037	.244	.062	.021	.67	5.90	.88	.15	13.6	21	88	do	A. H. 52–4, exp. 1.
4	.042	.034	.247	.065	.028	.63	5.95	.82	.14	13.2	21	90	do	A. H. 52–4, exp. 2.
5	.055	.038	.255	.075	.028	.73	4.65	.70	.15	14.1	21	93	do	A. H. 52–4, exp. 3.
7	.047	.026	.126	.030	.017	1.58	2.65	.55	.21	....	16	58	Washington	Hungate.
8	.049	.037	.256	.071	.025	.69	5.08	.75	.14	13.6	21	90	Valencia	A. H. 52–4, exp. 4.
10	.059	.038	.276	.082	.026	.72	4.70	.64	.14	13.6	21	90	do	A. H. 52–4, exp. 5.
11	.057	.034	.189	.015	.023	3.79	3.33	.60	.18	10.7	....	76	do	N. O. Co. Palmyr.
12	.069	.032	.272	.034	.021	2.02	3.98	.46	.12	12.6	21	93	Washington	A. H. 52–2.
13	.067	.045	.251	.041	.018	1.37	3.76	.68	.18	14.9	13	2	do	N. O. Co. Vict. 10
14	.076	.056	.229	.054	.028	1.41	3.00	.74	.25	11.2	21	91	Valencia	A. H. 63–3.
15	.078	.058	.262	.417	.024	.19	3.38	.74	.22	14.7	15	9	Thompson	N. O. Co. M. A. C.
16	.082	.033	.249	.018	.022	4.45	3.05	.41	.13	9.4	....	25	Washington	L. V. W. B., Oat. 5.
17	.084	.036	.213	.026	.030	3.23	2.54	.43	.17	12.0	....	33	do	L. V. W. B., Oat. 9.
18	.085	.034	.192	.053	.017	1.58	2.32	.41	.18	14.3	14	4	do	N. O. Co. Vict. Hill.
19	.086	.040	.192	.044	.022	1.95	2.22	.47	.21	10.6	14	30	Thompson	N. O. Co. Crouch.
20	.095	.036	.294	.018	.022	5.15	3.10	.38	.12	10.5	21	66	Washington	A. H. 62–1.
21	.091	.028	.183	.018	.023	5.20	2.00	.30	.15	10.2	....	68	do	L. V. W. B. Palmyr.
22	.093	.032	.195	.012	.022	7.95	2.10	.35	.17	12.1	....	70	Thompson	L. V. W. B. Low. Cer.
23	.099	.029	.199	.012	.026	8.45	2.01	.30	.15	11.5	....	55	do	L. V. W. B. Palmyr.
24	.091	.052	.355	.052	.014	1.76	3.91	.57	.15	11.1	23	73	Washington	N. O. Co. Shoem'k'r.
25	.093	.041	.236	.027	.023	3.48	5.53	.45	.18	16.4	12	12	do	N. O. Co. Vict. 20, exp. 10.
26	.100	.037	.263	.114	.043	.87	2.64	.37	.14	16.2	....	50	do	Elsinore Rd.
27	.104	.038	.250	.073	.026	1.43	2.40	.36	.15	12.5	21	71	Valencia	A. H. 80–4.
28	.106	.030	.236	.023	.021	4.75	2.21	.29	.13	9.8	21	85	do	A. H. 80–1.
29	.105	.052	.249	.055	.025	1.92	2.37	.50	.21	11.2	15	39	do	N. O. Co. Viv.
30	.105	.044	.228	.099	.023	1.06	2.18	.42	.19	16.3	13	21	Washington	N. O. Co. Vict. 20, exp. 9.
31	.108	.036	.184	.149	.020	.73	1.70	.34	.20	16.8	12	8	do	N. O. Co. Eur. 10.
32	.104	.029	.185	.018	.027	5.68	1.77	.28	.16	11.5	....	82	W. and V.	Viv.
33	.110	.039	.203	.010	.023	10.90	1.83	.35	.19	11.8	....	81	Valencia	L. V. W. B. Sun. Mt.
34	.110	.031	.201	.013	.018	8.20	1.83	.28	.16	10.8	....	37	do	L. V. W. B. Sun. Mt.
35	.117	.034	.230	.019	.020	5.13	1.95	.29	.15	9.7	21	56	Washington	A. H. 61–1.
36	.113	.034	.312	.025	.019	4.50	2.76	.30	.11	12.1	....	22	do	L. V. W. B., Oat. 8.
37	.104	.031	.226	.023	.026	4.44	2.18	.30	.14	12.4	....	50	do	L. V. W. B., Up. Cer.
38	.115	.043	.282	.018	.024	6.30	2.45	.37	.15	12.0	....	52	Washington	Hae. Sun. Mt.
39	.114	.053	.242	.040	.018	2.86	2.12	.46	.22	16.9	13	6	do	N. O. Co. Vict. 13.
40	.116	.044	.262	.025	.018	4.65	2.24	.38	.17	16.8	13	2	Valencia	N. O. Co. Vict. 8.
41	.119	.034	.280	.084	.017	1.41	2.36	.37	.12	16.4	13	Trace.	Washington	N. O. Co. Vict. 17.

TABLE I.—*Analyses of orange-grove soils in California to a depth of 3 feet*—Continued

No.	Percentage of— Humus.	Total nitrogen.	Organic carbon.	Carbonates.	Bicarbonates.	Ratio of— Humus to lime.	Carbon to humus.	Nitrogen to humus.	Nitrogen to carbon.	Moisture equivalent.	Trees. Age.	Percentage of mottled leaves.	Variety.	Location.
											Years.			
42	0.118	0.029	0.218	0.017	0.021	7.10	1.84	0.24	0.13	13.9	12	Trace.	Washington	N. O. Co. Eur. 7.
43	.122	.034	.201	.028	.033	4.46	1.63	.28	.17	11.5	13	18	Thompson	N. O. Co. Pach. 4.
44	.128	.038	.253	.039	.024	3.27	1.98	.30	.15	18.2	....	57	Washington	Colton Ave. Sm.
45	.097	.036	.270	.068	.030	1.42	2.38	.37	.14	15.5	....	55	....do	Colton Ave. Sm.
46	.132	.038	.267	.073	.025	1.82	2.02	.28	.14	16.3	13	32	....do	N. O. Co. Vict. 12, exp. 3.
47	.138	.046	.238	.104	.024	1.32	1.73	.34	.19	16.3	13	46	....do	N. O. Co. Vict. 12, exp. 5.
48	.134	.039	.212	.098	.020	1.34	1.58	.29	.19	16.5	13	11	....do	N. O. Co. Vict. 12, exp. 6.
49	.131	.039	.230	.033	.023	4.03	1.75	.30	.17	16.4	13	26	....do	N. O. Co. Vict. 12, exp. 8.
50	.136	.032	.240	.018	.022	7.75	1.77	.24	.13	12.5	12	10	....do	N. O. Co. Viv. Low. 3.
51	.146	.038	.315	.028	.023	5.28	2.17	.26	.12	11.8	....	32	....do	L. V. W. B., Oat. 7.
52	.142	.038	.274	.021	.032	6.80	1.93	.27	.14	13.1	13	19	....do	N. O. Co. Vict. 1 and 2.
53	.142	.037	.221	.098	.027	1.44	1.55	.26	.17	17.2	13	13	....do	N. O. Co. Vict. 20, exp. 7.
54	.144	.030	.259	.038	.018	3.82	1.81	.21	.12	10.8	12	Trace.	....do	N. O. Co. Eur. 12.
55	.143	.032	.246	.028	.024	5.20	1.72	.23	.13	12.7	12	3	Thompson	N. O. Co. Viv., Low. 1.
56	.141	.037	.244	.018	.022	7.67	1.73	.26	.15	12.7	12	8	....do	N. O. Co. Viv., Low. 2.
57	.150	.045	.228	.045	.023	3.33	1.53	.30	.20	10.9	12	5	Washington	N. O. Co. Viv., Low. 4.
58	.141	.034	.228	.079	.036	1.79	1.61	.24	.15	11.7	12	46	....do	N. O. Co. Flor.
59	.143	.038	.255	.836	.052	.17	1.78	.26	.15	6.0	....	53	....do	Bryn Mawr.
60	.142	.022	.139	.033	.013	4.37	.98	.16	.16	4.8	....	Trace.	....do	E. H., Redlands.
61	.156	.033	.289	.019	.019	8.16	1.85	.21	.12	11.8	....	58	Thompson	L. V. W. B., Dix.
62	.153	.044	.250	.071	.023	2.16	1.63	.29	.18	17.4	13	1	Washington	N. O. Co. Vict. 9.
63	.159	.043	.273	.074	.022	2.14	1.71	.27	.16	16.5	13	15	....do	N. O. Co. Vict. 20, exp. 2.
64	.156	.034	.243	.029	.018	5.35	1.55	.22	.14	15.3	12	Trace.	....do	N. O. Co. Eur. 9.
65	.154	.034	.260	.047	.029	3.30	1.69	.22	.13	10.5	12	50	....do	N. O. Co. Spring 2.
66	.152	.027	.201	.018	.026	8.37	1.32	.18	.14	12.1	....	56	....do	Vivi.
67	.159	.036	.278	.147	.031	1.08	1.75	.22	.13	16.6	....	67	....do	Colton Ave. Sm.
68	.169	.041	.291	.053	.026	3.20	1.73	.24	.14	11.5	....	44	....do	L. V. W. B., Oat. 4.
69	.162	.028	.193	.023	.021	6.94	1.19	.17	.14	9.7	....	42	....do	Viv.
70	.165	.043	.265	.562	.047	.29	1.60	.26	.16	8.7	....	95	....do	Bryn Mawr.
71	.163	.047	.309	.045	.027	3.62	1.89	.29	.15	12.4	....	59	....do	Bryn Mawr.
72	.162	.046	.220	.133	.022	1.23	1.36	.28	.21	13.5	....	8	....do	Redlands.
73	.177	.055	.248	.132	.013	1.35	1.39	.31	.22	15.4	13	1	....do	N. O. Co. Vict. 15.
74	.174	.045	.230	.148	.027	1.17	1.32	.26	.19	[illegible]7.2	13	67	....do	N. O. Co. Vict. 20, exp. 1.
75	.171	.042	.260	.104	.023	1.64	1.52	.24	.16	16.6	13	12	....do	N. O. Co. Vict. 20, exp. 4.
76	.178	.047	.245	.842	.052	.22	1.38	.27	.19	8.9	....	12	....do	Redlands.
77	.186	.048	.270	.031	.013	6.03	1.45	.26	.18	12.9	....	96	....do	Palm Ave., Redl.
78	.188	.037	.195	.003	.014	56.50	1.04	.20	.19	....	....	99	....do	Bloomington.
79	.182	.040	.350	.020	.025	8.95	1.93	.22	.11	14.1	....	64	Valencia	L. V. W. B., Dix.
80	.184	.032	.250	.026	.022	6.46	1.35	.17	.13	9.3	12	40	Washington	N. O. Co. Spring 1.

81	.190	.044	.268	.027	.032	7.13	1.40	.23	.16	15.4	13	Trace.	Thompson	N. O. Co., Vict. 14.
82	.198	.040	.282	.028	.029	6.30	1.41	.20	.14	15.0	13	1	....do	N. O. Co., Vict. 16.
83	.195	.056	.368	.030	.022	6.55	1.88	.30	.15	10.6	12	32	....do	N. O. Co., Viv. Up. 2.
84	.194	.038	.260	.031	.028	6.45	1.34	.19	.15	13.2	12	13	Washington	N. O. Co. Viv. Up. 6.
85	.198	.033	.223	.034	.028	5.83	1.02	.16	.15	12.7	12	14	....do	N. O. Co., Viv. Low. 8.
86	.209	.031	.223	.012	.023	17.80	1.11	.15	.14	8.4	....	28	Grapefruit	L. V. W. B., Dix.
87	.207	.047	.273	.033	.013	6.26	1.32	.23	.17	11.9	....	94	Navel	Citrus Ave. Redl'ds.
88	.212	.050	.274	.024	.016	8.80	1.29	.23	.18	12.7	....	36	....do	Citrus Ave. Redl'ds.
89	.215	.030	.177	.019	.018	11.20	.82	.14	.17	....	....	2	....do	Bloomington.
90	.211	.033	.226	.009	.019	23.00	1.07	.16	.15	12.0	12	Trace.	Washington	N. O. Co., Eur. 6.
90a	.218	.038	.288	.018	.023	11.84	1.32	.18	.13	13.0	....	65	....do	L. V. W. B., Dix.
91	.220	.039	.253	.031	.030	7.30	1.16	.18	.16	11.7	12	32	Grapefruit	N. O. Co., Viv. Up. 3.
92	.210	.030	.266	.019	.028	10.95	1.26	.14	.11	11.5	12	17	Washington	N. O. Co., Viv. Up. 5.
93	.221	.050	.299	.041	.023	5.18	1.35	.22	.17	13.8	....	4	Navel	Citrus Ave. Redl'ds.
94	.233	.038	.222	.010	.018	23.00	.95	.16	.17	9.1	....	3	Washington	Rod., Highland.
95	.239	.050	.358	.795	.055	.30	1.49	.21	.14	10.6	....	Trace.	Navel	Mull., Bryn Mawr.
96	.236	.039	.331	.021	.025	11.25	1.40	.17	.12	10.3	....	9	Washington	L. V. W. B., Oat. 6.
97	.232	.030	.278	.018	.032	12.65	1.18	.13	.11	11.3	12	14	Thompson	N. O. Co., Viv. Up. 4.
98	.245	.044	.284	.024	.021	10.10	1.16	.18	.15	11.8	....	46	Washington	Thomp., Highland.
99	.241	.037	.200	.014	.012	17.00	.83	.15	.18	8.4	....	None.	....do	Lin., Highland.
100	.244	.024	.134	.017	.017	14.60	.55	.10	.18	4.7	....	89	Navel	Men.
101	.271	.035	.266	.338	.032	.81	.98	.13	.13	7.1	....	61	Washington	A. E. F., Highland.
102	.279	.028	.240	.021	.018	13.40	.86	.10	.12	6.3	....	64	Navel	Azusa.
103	.282	.027	.199	.073	.010	3.89	.71	.10	.14	8.9	....	5	....do	G. C. L., Highland.
104	.287	.034	.277	.011	.028	26.40	.97	.12	.12	13.4	12	Trace.	Thompson	N. O. Co., Eureka 5.
105	.302	.041	.265	.021	.013	14.40	.88	.13	.15	10.0	....	39	Washington	L. V. W. B., Oat 1.
106	.313	.031	.207	.074	.023	4.20	.66	.10	.15	8.1	....	33	Valencia	Fr., Sun. Mt.
107	.333	.049	.408	.105	.028	3.17	1.22	.15	.12	9.2	....	90	Navel	Azusa.
108	.323	.042	.372	.011	.018	29.80	.97	.13	.13	7.9	....	12	Washington	L. V. W. B., Oat. 3.
109	.342	.036	.286	.008	.015	45.10	.84	.10	.13	7.7	....	12	Grapefruit	L. V. W. B., Sun. Mt.
110	.346	.027	.273	.034	.016	10.10	.79	.08	.10	9.7	....	5	Navel	Phy., Highland.
111	.342	.038	.310	.194	.017	1.76	.88	.11	.12	10.7	....	53	Washington	R. S. T., Highland.
112	.353	.040	.281	.035	.013	10.10	.80	.11	.14	9.1	....	76	Navel	Fl., Highland.
113	.373	.040	.288	.164	.023	2.38	.77	.11	.14	9.8	....	71	....do	A. E. F., Highland.
114	.378	.033	.282	.009	.014	42.00	.75	.09	.12	8.9	....	70	....do	Azusa.
115	.372	.026	.300	.012	.015	32.00	.80	.07	.09	7.5	....	10	Valencia	L. V. W. B., Sun. Mt.
116	.425	.043	.347	.016	.010	27.00	.82	.10	.13	8.7	....	None.	Nursery	R. S. T., Highland.
117	.431	.045	.499	.012	.022	37.00	1.15	.10	.09	10.9	....	23	Navel	Pomona.
118	.474	.041	.462	.026	.012	18.30	.98	.09	.09	8.1	....	None.	....do	Lock., Highland.
119	.503	.035	.427	.025	.018	20.00	.85	.07	.08	10.8	....	8	....do	Rod., Highland.
120	.506	.042	.332	.011	.015	46.50	.66	.08	.13	8.7	....	12	Washington	L. V. W.. B., Oat. 2.
121	.534	.052	.522	.033	.017	16.00	.98	.10	.10	13.0	....	None.	Navel	Ontario.
122	.557	.052	.589	.018	.013	30.60	1.05	.09	.09	7.9	....	None.	....do	Upland.
123	.584	.038	.287	.115	.018	5.10	.49	.07	.13	10.8	....	9	Washihgton	R. S. T., Highland.
124	.639	.040	.331	.057	.025	11.20	.52	.06	.12	7.1	....	19	Navel	Azusa.
125	.670	.060	.516	.107	.021	6.30	.77	.09	.12	15.0	....	None.	Valencia	Do.
126	.695	.067	.623	.015	.012	46.20	.91	.10	.11	21.2	....	Trace.	Navel	Do.
127	.769	.037	.298	.036	.012	22.40	3.87	.05	.12	9.7	....	90	....do	Pomona.

The results of the analyses of orange soils, together with the percentage of mottled leaves in each grove, are presented in Table I. In all cases, unless otherwise stated, the soil data given represent a sample 3 feet in depth. Each foot section to a depth of 3 feet was analyzed separately, but the results of the determinations on the individual foot sections disclose no relationships that are not equally well represented by the mean value. The analytical data from the orange groves were first considered in relation to soil type. While the soils around Redlands, Highlands, and Riverside differ to some extent in their physical characteristics, no correlation between mottle-leaf and soil type was in evidence. Furthermore, the fact that mottling seems to be about equally advanced on all the soil types of this area, other conditions, as age of grove, general treatment, etc., being the same, would indicate prima facie that the soil type is by no means a controlling factor. The results obtained from all the orange groves studied in the districts around Riverside, Redlands, Highland, and Rialto are therefore presented collectively. A few groves studied around Pomona, Ontario, and Azusa are not included in this grouping, since the soil conditions of these districts are quite different, in so far at least as the organic content is concerned.

To facilitate further comparison, the orange-grove data are grouped in Table II on the basis of the percentage of mottling. Each group represents the average of about 20 groves, so that each point on the accompanying graphs represents an average of about 60 separate determinations of a given factor, and approximately 200 mottling determinations.[1] The fact that mottling is not dependent upon the texture of the soil is again emphasized in this table, which shows that the moisture retentiveness of the several groups as measured by the moisture equivalent[2] is very nearly the same.

TABLE II.—*Analysis of orange-grove soils near Riverside, Redlands, Highland, and Rialto, Cal., grouped according to percentage of mottled leaves, each group containing approximately 20 groves*

Group.	Percentage of—					Ratio of—				Moisture equivalent.	Mottled leaves.
	Humus.	Total nitrogen.	Organic carbon.	Mineral carbonates.	Mineral bicarbonates.	Humus to lime.	Carbon to humus.	Nitrogen to humus.	Nitrogen to carbon.		
										Per cent.	*Per cent.*
1	0.119	0.036	0.237	0.069	0.023	1.72	2.50	0.303	0.152	11.3	88
2	.142	.036	.256	.066	.024	2.15	1.54	.254	.141	12.4	64
3	.170	.039	.254	.093	.026	1.83	1.67	.229	.154	11.6	43
4	.165	.039	.255	.080	.027	2.06	1.65	.237	.153	12.6	19
5	.244	.039	.261	.068	.020	3.59	1.93	.159	.149	11.9	5
6	.204	.038	.263	.079	.028	2.58	1.78	.186	.144	12.8	7

[1] The ratios in Tables II and IV are calculated from the mean values of the measured factors.

[2] The moisture equivalent is a measure of the moisture retentiveness of a soil, and is numerically equal to the percentage of moisture which a given soil is able to retain in opposition to a centrifugal force 1,000 times that of gravity. The finer the soil particles the greater is the moisture equivalent.

RELATION OF "HUMUS" IN SOIL TO LEAF MOTTLING OF ORANGES

The relation of the percentage of leaf mottling to the percentage of humus in the soil is shown in figure 1, the humus being plotted as the abscissas and the mottling as ordinates. While the points by no means form a smooth curve, there is a very evident inverse relation, showing that a high humus content is correlated with a low percentage of mottling.

As already mentioned, some time is required for an orange or lemon tree to respond to an application of manure. Consequently, in cases where manure has been recently added to a grove a measurable increase in humus may result without sufficient time having elapsed for a leaf response. Furthermore, when a leaf is well advanced in mottling, it does not recuperate (except by special leaf treatment), but remains mottled until it drops. Hence, a new set of leaves must be grown before the mottling will disappear from the tree, although the first stage of mottling, especially in a young leaf, may disappear as the leaf grows, if conditions become favorable. With these facts in mind, one would expect that the humus graph presented in figure 1 would show some inconsistencies, especially since other soil factors besides humus undoubtedly influence the nutrition of the tree.

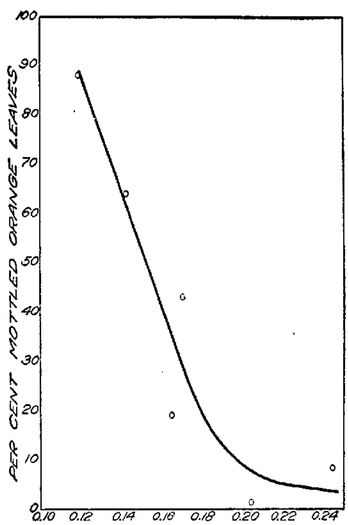


FIG. 1.—Graphical presentation of the relationship between humus content of soil and percentage of mottled orange leaves (from data in Table II).

The relationship between humus and mottling has been examined in more detail by the use of statistical methods. The form of the graph in figure 1 suggests an approximate hyperbolic relationship between humus content and mottling. In order to reduce the data to a suitable linear form for calculating the coefficient of correlation, the reciprocal of the humus content of each soil was calculated—that is, the number of grams

of soil required to include 1 gm. of humus. The coefficient of correlation between this quantity and the percentage of mottled leaves for all the orange groves included in the main group was found to be 0.67 ± 0.03. The association would be represented by the square of this quantity, or 0.45. In other words, approximately one-half of the mottling can be accounted for by the low humus content of the soil. This conclusion is reached from a consideration of the data by impartial statistical methods and is free from personal bias.

The failure of the trees in some cases to respond to manure appears to be due to the methods of cultivation and irrigation employed. It has been the general practice in California orange culture to maintain a deep dust mulch in the groves by cultivating frequently during the summer months. In fact, the cultivation which is carried on between irrigation periods, combined with the opening and closing of irrigation furrows, results in working the surface soil on an average of nearly once a week during the summer months. It is quite impossible for any effective root development to take place in this surface layer under such conditions. The roots are destroyed by the constant cultivation; and owing to the frequent stirring, the soil during the greater part of the time is entirely too dry for root development. Yet this is the part of the soil to which manure is applied, the usual practice being to disk the manure into the mulch. Even when the manure or a cover crop is plowed under, the plowing is often so shallow that the material turned under is within reach of the teeth of the cultivator. The result is, therefore, that the organic matter is partly disintegrated and lost without ever coming in contact with the feeding roots of the tree. Under such conditions it is not surprising that little benefit has resulted from the use of manure. It would be difficult to conceive a more effective method for the rapid destruction of the organic matter than the repeated stirring, moistening, and drying to which it is subjected in this deep surface mulch.

The difference in humus content between the soils of the badly mottled groves and those relatively free from mottling is about 0.1 per cent. This difference may at first sight appear small; but when expressed in terms of the weight of the soil, its magnitude becomes apparent. An acre of soil 3 feet in depth weighs approximately 10,000,000 pounds, so that a humus content of one-tenth of 1 per cent is equivalent to 10,000 pounds of humus. Data regarding the amount of humus formed from a ton of organic matter are not at present available, but manure would probably not often yield more than 10 per cent, or 200 pounds of "humus", or "*matière noire*", per ton. On the basis of this assumption it would require an application of at least 50 tons of manure per acre to bring the humus content of the badly mottled groves up to that of the groves relatively free from mottling.

Mention has already been made of the fact that the appearance of the mottled leaves indicates that the mottled Citrus tree is failing to secure something essential in the formation of chlorophyll. The association between mottling and low humus suggests that the missing substance may be some organic compound normally formed during the decomposition of organic matter in the soil or associated with the formation of humus, in which event the "humus" content would be indicative to some extent of the amount of this substance formed. Until further information is available in this connection, practical considerations point to the immediate enrichment of the humus content of the soil as the most promising specific for mottle-leaf.

RELATION OF MINERAL CARBONATES TO MOTTLING OF ORANGE TREES

The mineral carbonates in the soils of the area studied consist for the most part of calcium carbonate (limestone). The percentage is usually low (see Table I), although large deposits of limestone are found in some of the hills rising from the floor of the valley. No significant correlation was found to exist between the percentage of mineral carbonates and the percentage of mottled leaves (correlation coefficient $=0.07 \pm 0.06$). In other words, there is no evidence that the amount of mineral carbonates within the limits found in these soils bears any relation to mottling. Most of the groves in the areas studied have not been limed, and where lime has been used, the amount applied has with few exceptions been so small as to be negligible in the determinations. For example, an application of a ton of limestone per acre would mean an increase of only two one-hundredths per cent when calculated on the weight of the soil to a depth of 3 feet. The effect of heavy applications of lime on mottling has not yet been definitely settled by properly controlled field experiments. This matter should furthermore not be confused with the evident beneficial effect of lime in improving the physical condition of some of the soils in the area studied.

RATIO OF HUMUS TO MINERAL CARBONATES AS AFFECTING MOTTLING OF ORANGE TREES

The ratio of humus to mineral carbonates in orange groves is plotted in figure 2 against the percentage of mottling. While the relationship is not marked, the mottling tends to diminish as the humus-lime ratio increases. The correlation between the reciprocal of this ratio and the mottling was computed and found to be 0.17 ± 0.06. Since no relationship was observed between the lime content of the soil and the percentage of mottling, it seems probable that the correlation observed in the case of the humus-lime ratio is dependent wholly on the humus correlation. The result indicates that the humus content of the soil should be taken

into consideration in applying lime and that such treatment would be more likely to be beneficial in the case of soils with a high humus content.

RELATION OF ORGANIC CARBON TO MOTTLING OF ORANGE LEAVES

The correlation between the total organic carbon in the soil and the leaf mottling is very low (-0.10 ± 0.06). Organic matter is not effective in nutrition until decomposition has set in, and the results indicate that the amount of those decomposition products effective in the control of mottle-leaf and available in the soil at a given time is not necessarily proportional to the total organic carbon present. The negative sign of the correlation coefficient shows that the mottling tends to decrease as the organic matter increases.

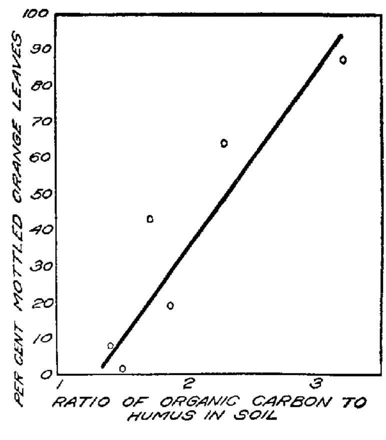


FIG. 2.—Graphical presentation of the relationship between the ratio of organic carbon to humus in the soil and the percentage of mottled orange leaves (from data in Table II).

RATIO OF ORGANIC CARBON TO HUMUS IN RELATION TO MOTTLING OF ORANGE LEAVES

The data presented in Table II for the six groups of orange groves show that an increase in the ratio of organic carbon to humus is accompanied by an increase in mottling (fig. 3). This relationship may be partly due to the fact that the mean organic content of the soils of the several groups is nearly the same throughout, although the reduction in mottling is accompanied by a slight increase in organic carbon.

A correlation of 0.43 ± 0.06 was found between the organic carbon-humus ratio and the percentage of mottling. While this correlation may be partly associative, as in the case of the lime-humus ratio, the results indicate that it is important in the nutrition of the orange tree that the organic matter be decomposed, so far as possible, into humus, since the greater the proportion of humified organic matter, the smaller the percentage of mottling. This, of course, does not necessarily indicate that what we term "humus" is the most effective form of organic matter for promoting a healthy growth of orange leaves; but if a

soil can properly humify organic matter, the latter will apparently go through the decomposition stages most beneficial to the growth of the tree.

NITROGEN CONTENT AND MOTTLING

The total nitrogen content in the soil was surprisingly uniform regardless of grove conditions and soil types. The variation in total nitrogen within the limits found in the soils of the groves examined appears to bear no relation to the percentage of mottling (correlation coefficient = -0.02 ± 0.06). A part of the nitrogen is undoubtedly held in a form not immediately available to the tree and in this respect is somewhat analogous to the total organic carbon in the soil. When the orange soils are grouped on the basis of mottling, as in Table II, the two most badly mottled groups show the lowest average nitrogen content, but the differences are so small as to have little significance. The other groups will be seen from Table II to have practically the same average nitrogen content. Such relationship as exists may be due to the fact that part of the total nitrogen is combined as "humus," so that the low humus soils would be lower in nitrogen.[1]

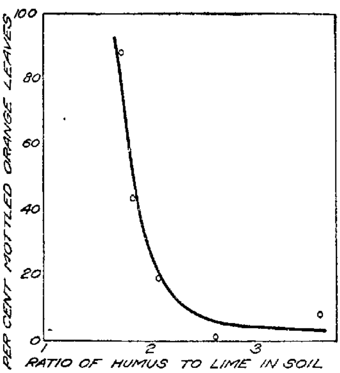


FIG. 3.—Graphical presentation of the relationship between the ratio of humus to lime in the soil and the percentage of mottled leaves (from data in Table II).

LEMON SOILS

The field studies of the lemon groves were carried on in a manner similar to that of the orange groves. The lemon groves selected all belong to the same company and constitute the principal lemon groves in the Riverside district. The data for the individual groves are presented in Table III and are grouped on the basis of mottling in Table IV.

[1] For data regarding the nitrate content of the soils of the Riverside area, see Kellerman, K. F., and Wright, R. C. Relation of bacterial transformations of soil nitrogen to nutrition of citrous plants. *In* Jour. Agr. Research, v. 2, no. 2, p. 101-113, 7 fig. 1914.

TABLE III.—*Analyses of lemon-grove soils in California to a depth of 3 feet*

No.	Percentage of—					Ratio of—				Moisture equivalent.	Trees.		
	Humus.	Total nitrogen.	Organic carbon.	Carbonates.	Bicarbonates.	Humus to lime.	Carbon to humus.	Nitrogen to humus.	Nitrogen to carbon.		Age.	Percentage of mottled leaves.	Location.
1..	0.044	0.031	0.265	0.041	0.028	1.08	6.00	0.70	0.12	11.5	20	88	A. H. 32 -35
2..	.045	.035	.275	.058	.025	.77	6.14	.78	.13	10.5	20	93	A. H. 32 -42
3..	.047	.031	.260	.069	.026	.68	5.48	.68	.12	12.6	21	44	A. H. 80 - 6
4..	.058	.030	.215	.032	.019	1.81	3.72	.53	.14	6.8	20	63	A. H. 32 -40
5..	.059	.028	.214	.090	.023	.65	3.62	.48	.13	9.5	20	79	A. H. 25½- 8
6..	.057	.033	.263	.197	.033	.29	4.65	.58	.13	12.0	21	76	A. H. 56 - 6
7..	.058	.034	.275	.058	.026	1.01	4.80	.59	.13	12.8	23	85	A. H. 46 - 6
8..	.069	.031	.212	.075	.025	.92	3.10	.46	.15	11.0	9	59	A. H. 32 -38
9..	.066	.032	.234	.063	.026	1.04	3.58	.49	.14	10.2	21	89	A. H. 32 -43
10..	.068	.028	.244	.054	.025	1.25	3.60	.42	.12	11.4	21	89	A. H. 32 -34
11..	.066	.039	.249	.077	.029	.66	3.80	.59	.16	13.2	21	59	A. H. 80 - 4
12..	.069	.045	.295	.045	.024	1.54	4.26	.65	.15	15.1	23	81	A. H. 45 - 8
13..	.070	.032	.244	.077	.024	.91	3.52	.47	.13	9.8	23	93	A. H. 32 - 7
14..	.066	.032	.236	.027	.021	2.40	3.55	.49	.18	11.0	23	91	A. H. 32 -34
15..	.064	.029	.226	.075	.023	.86	3.54	.45	.13	8.3	21	90	A. H. 17 - 1
16..	.067	.029	.258	.053	.026	1.26	3.85	.43	.11	12.0	21	86	A. H. 56 - 4
17..	.069	.023	.280	.166	.041	.41	4.10	.34	.08	13.7	21	68	A. H. 56 - 1
18..	.062	.031	.278	.075	.030	.81	4.47	.50	.11	11.8	21	76	A. H. 46 - 5
19..	.068	.036	.265	.086	.025	.81	3.90	.53	.14	11.3	21	76	A. H. 18 - 4
20..	.070	.026	.316	.089	.031	.67	4.55	.37	.08	12.0	21	83	A. H. 54 - 1
21..	.072	.029	.243	.086	.024	.84	3.36	.38	.12	9.6	21	94	A. H. 32 -44
22..	.074	.031	.242	.066	.022	1.11	3.28	.43	.13	13.6	21	56	A. H. 80 - 3
23..	.079	.030	.228	.032	.019	2.48	2.88	.38	.13	8.2	21	89	A. H. 25½- 6
24..	.076	.029	.221	.041	.014	1.85	2.91	.38	.13	9.7	21	94	A. H. 17 - 3
25..	.071	.043	.286	.244	.038	.29	4.04	.60	.15	14.9	21	70	[a]A. H. 56 - 7
26..	.071	.037	.282	.122	.034	.58	3.96	.52	.13	13.8	21	56	A. H. 56 - 2
27..	.071	.033	.278	.097	.038	.71	3.82	.47	.12	13.8	23	67	A. H. 46 - 4
28..	.078	.033	.282	.138	.033	.57	3.63	.42	.12	11.5	19	80	A. H. A3 - 3
29..	.083	.039	.202	.029	.032	.84	2.44	.47	.19	13.3	9	72	A. H. 32 -21
30..	.081	.028	.197	.028	.030	2.92	2.44	.35	.14	7.0	21	77	A. H. 32 -51
31..	.082	.043	.247	.098	.033	.82	3.00	.53	.18	......	21	85	A. H. 74 - 3
32..	.089	.028	.190	.028	.021	3.24	2.12	.32	.15	6.9	21	82	A. H. 32 -50
33..	.082	.043	.240	.098	.033	.82	2.92	.53	.18	......	21	46	A. H. 74 - 2
34..	.089	.027	.274	.033	.024	2.72	3.04	.30	.10	10.8	21	86	A. H. 80 - 2
35..	.089	.036	.272	.083	.024	1.08	3.06	.40	.13	7.4	21	59	[b]A. H. 56 - 7
36..	.081	.041	.265	.084	.028	.97	3.26	.50	.15	12.9	21	85	A. H. 53 - 2
37..	.092	.028	.239	.018	.021	5.00	2.60	.30	.12	9.8	21	82	A. H. 25½- 4
38..	.094	.028	.190	.033	.019	2.80	2.03	.30	.15	8.4	21	79	A. H. 25½- 2
39..	.097	.043	.315	.074	.038	1.31	3.25	.45	.14	14.2	21	82	A. H. 45 -10
40..	.103	.033	.238	.049	.023	2.10	2.30	.32	.14	8.6	21	87	A. H. 18 - 3
41..	.117	.046	.230	.087	.030	1.16	1.97	.40	.20	13.0	23	84	A. H. 45 - 9
42..	.127	.036	.258	.048	.019	2.78	2.04	.28	.14	7.8	20	88	A. H. 32 -32

[a] Upper. [b] Lower.

TABLE IV.—*Analyses of California lemon-grove soils, grouped according to percentage of mottled leaves, each group including eight groves*

Group.	Percentage of—					Ratio of—				Moisture equivalent.	Mottled leaves.
	Humus.	Total nitrogen.	Organic carbon.	Mineral carbonates.	Mineral bicarbonates.	Humus to lime.	Carbon to humus.	Nitrogen to humus.	Nitrogen to carbon.	*Per cent.*	*Per cent.*
1...........	0.066	0.036	0.241	0.062	0.023	1.06	2.74	0.545	0.149	10.1	[illegible]
2...........	.081	.033	.258	.050	.024	1.64	3.18	.407	.128	10.5	[illegible]
3...........	.087	.037	.265	.073	.029	1.19	3.05	.425	.139	11.8	[illegible]
4...........	.072	.033	.237	.097	.029	.74	3.29	.458	.139	11.0	[illegible]
5...........	.070	.033	.253	.089	.029	.79	3.61	.471	.126	11.8	[illegible]

RELATION OF HUMUS IN THE SOIL TO MOTTLING OF THE LEMON LEAVES

It was found that the humus content of the soil in the orange groves varied inversely with the leaf mottling. In the case of the lemon groves no definite relation appears at first sight to exist between these two factors. However, a comparison of Table II with Table IV shows that the humus content of most of the orange groves was much higher than that of the lemon groves. It will be noted from Table IV that the humus content of the lemon-grove groups was in every case less than one-tenth of 1 per cent, an extremely low value. Orange groves in which the humus content approximates 0.1 per cent (Table II) show as high a percentage of mottling as the lemon groves. It would therefore appear that the humus content in the lemon groves is less than is necessary for the growth of a leaf comparatively free from mottling, assuming that lemon leaves would mottle to the same extent as orange leaves under the same conditions.

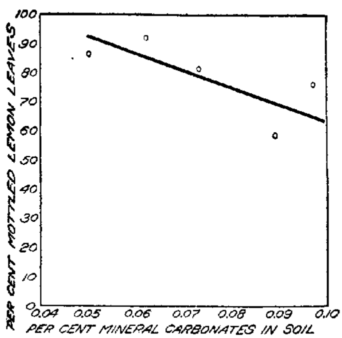


FIG. 4.—Graphical presentation of the relationship between the mineral carbonates in the soil and the percentage of mottled lemon leaves (from data in Table IV).

RELATION OF MINERAL CARBONATES IN THE SOIL TO LEAF MOTTLING

An indication of a slight relationship between the mineral carbonate content of the soil and the percentage of mottled leaves was obtained in the case of the lemon groves, as shown in figure 4. The correlation coefficient is $-0.31 + 0.09$, the minus sign indicating that the mottling decreases as the mineral carbonates (chiefly lime) increase. This correlation coefficient would indicate an association between mottling and lime content of about 10 per cent. The probable error is relatively so large that the result can be considered to be little more than indicative of the inverse character of the relationship. The percentage of mottling is very high even in the case of the highest lime content. The average amount of lime carbonate in the lemon-grove soils was about the same as in the orange-grove soils.

It is recognized that the lime-carbonate content is very low in all the soils represented in these areas and possibly a higher range of this constituent would bring out more definite results. The data presented are not sufficient to justify recommending the application of lime to lemon

groves which are low in this constituent, but lime experiments with the lemon would appear to be more promising than with the orange, other conditions being the same.

No correlation was found to exist between organic carbon or total nitrogen and mottling, the correlation coefficient in each case being no greater than the probable error.

SUMMARY

Mottle-leaf of Citrus trees is characterized by the disappearance of chlorophyll from parts of the leaf, the portions farthest removed from the midrib and larger veins being first affected. As the disturbance progresses, the yellowish spots increase in size until the only remaining chlorophyll is confined to narrow areas along the midrib and the larger veins. The advanced stages are accompanied by a marked decrease in the size, quality, and yield of fruit. No organism has yet been proved to be causally associated with mottle-leaf, but the Citrus-root nematode has been found by Thomas to be widely distributed in mottled districts.

Mottle-leaf is found in most Citrus-fruit sections of California, but is more prevalent in some districts than in others. All the Citrus fruits grown in California are affected, including the Washington Navel, Thompson Improved Navel, and Valencia orange, grapefruit, tangerine, and lemon.

The conclusions of the present paper are based upon a field and laboratory study of 130 orange groves and 45 lemon groves, located mainly in Riverside and San Bernardino Counties, Cal. The percentage of mottled leaves was determined by examining 10 to 12 typical trees in each grove. A soil sample 3 feet in depth was taken near each tree, each foot sample being kept separately. These samples were analyzed for humus, organic carbon, mineral carbonates, bicarbonates, and total nitrogen.

During the earlier stages of mottling no serious reduction in yield was observed. The fruit yield was apparently not seriously reduced on either orange or lemon trees which had about 20 per cent of their leaves mottled. Sour-orange stock was found to induce more severe mottling in orange trees than sweet-orange stock, other conditions being the same. A mixed grove of Washington Navel and Valencia oranges showed no difference in the amount of mottling of these two varieties.

Badly mottled orange trees cut back and rebudded on the stumps produce badly mottled new top growth; and unless the soil treatment of such groves is changed, the mottling persists.

There was no noticeable difference in the amount of leaf mottling in groves on different soil types, other conditions being the same.

Orchards fertilized with organic substances, such as stable manure or cover crops plowed under, usually showed less mottling than groves supplied principally with commercial fertilizers. Groves which for some years had received only the "complete" fertilizers in general use in the

areas studied were badly mottled in all cases, so far as observed in these studies. This was also the case where sodium nitrate was used alone or as the principal fertilizer for some years.

The results of the soil analyses show in the case of oranges a marked inverse correlation between the humus content of the soil and the percentage of mottling, the latter tending to diminish as the humus content increases. An impartial statistical study of the data from the individual orange groves shows that approximately one-half the mottling can be accounted for by the low humus content of the soil.

The humus content of the lemon soils studied is much below that of most of the orange soils, averaging less than 0.1 per cent. This amount of humus is apparently too low to produce a normal foliage growth, all of the lemon groves being badly mottled.

No correlation was found between the mineral carbonates of the soil and the mottling of orange trees. In lemons the mottling decreased slightly as the mineral carbonates increased, but the correlation is low. The lime content of nearly all the Citrus soils studied is low, and the effect of heavy applications of lime can only be determined by suitably controlled field experiments. The present study indicates that the application of lime would be more likely to benefit lemon trees than orange trees.

The percentage of mottled leaves on orange trees is definitely correlated with the increase of the ratio of organic carbon to humus, indicating the importance of the organic matter in the soil being well decomposed.

No relation was found between the percentage of leaves mottled and the total nitrogen content in the soil in either the orange groves or the lemon groves studied.

The principal conclusion of this investigation is that the mottling of orange trees in the areas studied is definitely correlated with the low humus content of the soil, the mottling diminishing as the humus content increases. A study of the data by statistical methods shows that approximately one-half of the mottling can be accounted for on this basis. The incorporation of organic matter with the soil in such a manner as to be accessible to the roots during its decomposition is indicated as a promising treatment for mottle-leaf.

PLATE H

Various stages in mottle-leaf of the orange.

(740)

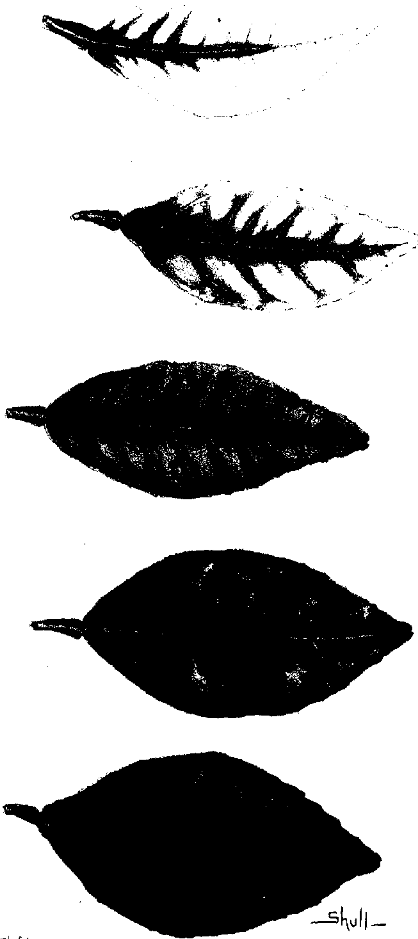

Shull

PLATE XCVI

Orange leaves showing mottle-leaf.

PLATE XCVII

A more advanced stage of mottle-leaf of orange, showing the reduction in the size of the leaves.

VEGETATIVE SUCCESSION UNDER IRRIGATION

By J. FRANCIS MACBRIDE [1]

Agricultural Experiment Station of the University of Wyoming

INTRODUCTION

The data given in the following pages are compiled from observations made during the growing seasons of 1912, 1913, and 1914, on a ranch situated near Rock River, Albany County, Wyo., in the southeastern part of the State. The Union Pacific Railroad makes the altitude at the station 2,105 meters. As the part of the ranch with which we are concerned lies about 3 miles up Rock Creek, the altitude will approximate 2,134 meters, a figure that corresponds very well with the general elevation of the Laramie Plains (including the Laramie Basin), of which this is a section.

Several years ago the hay yield of the ranch, obtained entirely from the natural meadow lands, fell short of the consumption. Means were taken to increase the hay acreage by the transformation of bench land to meadow, a transformation accomplished simply by flooding during the successive growing seasons. This method has proved so successful that each succeeding year has seen greater and greater areas flooded until now large reservoirs (Pl. CI, fig. 2) are required to augment the water supply during the midsummer season.

Of course it takes several seasons to complete this change, and the following notes are the result of a study of the various phases of vegetation through which the bench land passes in this transition to meadow. At the time these observations were made (1913 and 1914) several adjoining tracts, each flooded for the first time in a different season, furnished an unusual opportunity for the comparison and study of their development from year to year and at the same time gave striking physical evidence of actual differences in the vegetation present. I refer to the varying tones of green which the different tracts assumed as the season advanced—a condition so marked that with a very little practice one could ride over the ranch and state authoritatively that this section has been under water for four years, this for two, and so on. Indeed, it was this beautiful blotching of the landscape with various shades of green and brown that led to the discovery of what was really happening.

[1] This work was done under the direction of Dr. Aven Nelson, of the Wyoming Experiment Station. If the conclusions, based on a study that was conceived in a spirit of helpfulness, prove of value, the credit can not be too largely assigned to the active interest and kindly encouragement of my adviser. The distressing difficulties under which the photographs were secured could not have been overcome except by Dr. Nelson's perseverance and constant help. I wish to thank Prof. A. S. Hitchcock, of the United States Department of Agriculture, for determining my material of the genus Agropyron; also Mr. V. H. Rowland, who furnished the determinations of the difficult genus Carex.

A collection of plants illustrating the salient features of the Rock Creek upland and meadow floras and substantiating the points brought out in this study is deposited in the Rocky Mountain Herbarium at Laramie, Wyo.

GEOLOGY OF ROCK CREEK REGION

The geological formation[1] belongs to the lower part of the Montana group of the Cretaceous, characterized by sandstones and carbonaceous shales with local coal deposits. The depth of this deposit is said to average over 305 meters, and there is no evidence that Rock Creek has more than scratched the surface, so the soil of the region is of nearly uniform character. Sandstones beneath the coal contain various fossils of particular interest, because about 50 per cent belong to genera represented there to-day, as cottonwood (*Populus* spp.), alder (*Alnus* spp.), birch (*Betula* spp.), willow (*Salix* spp.), and others. The rather soft surface shales and sandstones are occasionally exposed, but more frequently are covered with a fine gravel wash, somewhat disguised by reason of the growth of short grasses and xerophytic shrubs. These remarks, of course, apply only to the land above the stream. Rock Creek, like all the streams in the Laramie Basin, flows through a valley varying in width and filled with alluvial deposits, in many places 50 to 60 feet deep. The character of the upland soils is also typical of a great deal of the Laramie Basin, so that from an agricultural standpoint the results of this study are applicable to a much larger region than that in which the actual observations were made.

CLIMATE OF ROCK CREEK REGION

The climate of Rock Creek is essentially that of the Laramie Basin. Meteorological records kept at the State University at Laramie since 1891 show an average rainfall of about 10 inches and a mean annual temperature of about 40° F. The monthly averages for 15 years are given in Tables I and II.

TABLE I.—*Monthly means of precipitation (in inches) at Laramie, Wyo., 1891–1905*

January	0.23	May	1.47	September	0.92
February	.34	June	1.24	October	.79
March	.83	July	1.40	November	.22
April	1.14	August	.99	December	.33

TABLE II.—*Monthly means of temperature (°F.) at Laramie, Wyo., 1891–1905*

January	21.6	May	47.4	September	51.8
February	20.3	June	56.6	October	42.1
March	28.4	July	62.3	November	31.1
April	37.3	August	61.9	December	21.8

The higher temperatures are of short duration, and the maximum rarely reaches 90° F. All the nights are cool. The flora is thus, of necessity, composed of plants that have become adapted not only to the low average temperature and the aridity of the plains but also to the

[1] Darton, N. H., and Siebenthal, C. E. Geology and mineral resources of the Laramie Basin, Wyo. A preliminary report. U. S. Geol. Survey Bul. 364, 81 p., 2 pl. 1909.

short season; for although September often draws to a close before the first killing frost, the next June may be half gone before the cottonwoods along the streams have flaunted anything like full-grown leaves. Of course, grasses and bulbous and thick-rooted perennials have beautified the plains with flower or verdure long before the last frost is out of the meadow lands, or at least before the spring freshets have subsided enough to permit the growth of the meadow plants.

PHYSIOGRAPHY OF ROCK CREEK REGION

Physiographically the Rock Creek ranch is divisible into four regions or units which for convenience may be designated and defined as follows: (1) The stream valley (Pl. XCVIII), practically synonymous to the flood plain of the creek and characterized by the natural meadows, willow thickets, swamps, and cottonwood timber; (2) the bench slope (Pl. XCIX; C, fig. 1), representing the sides of the stream valley; (3) the draws, or gullies (Pl. C, fig. 2), occurring on the bench proper and breaking through the bench slope at intervals; and (4) the bench land (Pl. CI, fig. 1), flat, short-grass, upland plains.

A knowledge is needed, of course, of the original flora of the flooded lands, in order to comprehend the changes in vegetation which are going to take place in some of the regions as the result of irrigation. Accordingly the immediately succeeding paragraphs are devoted to a description and to an analysis of this flora.

PHYTOGEOGRAPHY OF ROCK CREEK REGION

The lists of plants under "Phytogeography of Rock Creek region" represent only those that contribute a present or later value toward the working out of the problem in hand. For additional species noted, mostly of interest only to the botanist, the reader is referred to the lists of minor plants on pages 757–758. In some instances plants here referred to under their generic name are given their specific designations later and in these instances will not be found in the supplementary lists.

BENCH FLORA

CHARACTERISTIC BENCH-LAND PLANTS

Agropyron spp. (four species).	*Oxytropis monticola* Gray.
Buchloe dactyloides (Nutt.) Engelm.	*Pentstemon angustifolius* Pursh.
Oryzopsis hymenoides (R. and S.) Ricker.	*Chrysothamnus frigidus* Greene.
Eurotia lanata (Pursh) Moq.	*Artemisia frigida* Willd.
Potentilla effusa Dougl.	*Lygodesmia juncea* Don.
Astragalus spp. (five species).	*Tetradymia inermis* Nutt.

The ecologist will note plants in this list representative of well-known plant associations, such as the short-grass and the wheat-grass; the purpose of these lists, however, is not to classify the plants of a given physiographic unit but rather to treat such plants as a complex the limits of which are

determined purely by the bounds of the unit, as indicated above. Since these bounds are of more or less arbitrary definition in themselves, the disposition of plants within them is of like nature, though it may be said that, in general, the fullest development of a given species normally occurs within the unit in which it is placed.

Any one of the four wheat-grasses may be dominant or principal species—that is, it may make up the bulk of the vegetation over large areas of this unit (Pl. CII, fig. 2). The kind with which we are most concerned, however, reaches its best development in another complex.

Indian millet (*Oryzopsis hymenoides*), though of great importance from a nutritive standpoint,[1] is largely confined to loose, somewhat sandy soils; and therefore its possibilities for forage development are limited to regions of that nature.

Attention is called to the large number of legumes in this complex—five kinds. These will be augmented by five more, distributed among the remaining complexes. Legumes require rich soils of high lime content, the significance of which will develop later.

The remaining plants are nearly all xerophytes, species eminently fitted in one way or another to withstand the rigors of the environment in which they live. It is not surprising that such plants will take no part in an artificial transformation of this bench to meadow, where new conditions are suddenly introduced which are directly opposed to those to which these species have become so well adapted. Their disappearance in many cases means the loss of the most nutritious plants on the range.

CHARACTERISTIC DRAW, OR GULLY, PLANTS

Bouteloua oligostachya (Nutt.) Torr.	*Astragalus* spp. (two species).
Koeleria cristata (L.) Pers.	*Lupinus parviflorus* Nutt.
Stipa comata Trin. and Rupr.	*Antennaria parvifolia* Nutt.
Carex spp. (two species).	*Artemisia cana* Pursh.
Zygadenus intermedius Rydb.	*Grindelia subalpina* Greene.
Delphinium Geyeri Greene.	

The bench lands are interrupted at irregular intervals by swales, or draws. These carry away the surplus surface water to the stream, so that those that drain a considerable area become gulches. Plate C, figure 2, gives a good average idea of this topographical feature. The chief difference, as compared to the bench proper, is the more constant water supply, which is somewhat greater and which lasts longer. It is not surprising, therefore, that over 69 per cent of its more characteristic plants (as given above) will persist (in some cases attain greater development) during the first season under irrigation.

Among those that will not be able to stand the new conditions are *Delphinium Geyeri* and *Zygadenus intermedius*, both a constant menace to

[1] Knight, H. G., Hepner, F. E., and Nelson, Aven. Wyoming forage plants and their chemical composition—Studies no. 3. Wyo. Agr. Exp. Sta. Bul. 76, 119 p., 50 fig. 1908.

stock because of poisons they contain. The latter is peculiar in its habitat relations. It appears in drier parts of meadows that have been established for several years, but does not seem to stand the sudden change to meadow conditions. This may be explained by the fact that it grows in the lower parts of the draw, where the change in moisture content becomes greatest. When it later invades the meadow, places frequently exist that more nearly conform to its usual habitat. At any rate, the new meadows are free from it for some time.

CHARACTERISTIC BENCH-SLOPE PLANTS

Agropyron Smithii Rydb.	*Potentilla pennsylvanica* L., var. *strigosa* Pursh.
Elymus condensatus Prsl.	*Astragalus* spp. (three species).
Delphinium Menziesii DC.	*Solidago concinna* A. Nels.
Arabis hirsuta Scop.	

The change from upland to lowland is very abrupt, as shown in Plates XCI and C, figure 1. The conditions are in many respects similar to those of the preceding region, except that the water supply is greater and even more constant. This permits the growth of various mesophytic herbs and shrubs (for lists of these see pp. 757–758.) The upper part of the slope is more or less like the bench, depending upon the local variation in the abruptness of the incline. Therefore the bench-slope plants can not be satisfactorily segregated from those of other units, since species characteristic to them find within the borders of the bench slope entirely suitable habitats.

Agropyron Smithii prefers a more constant water supply than its relatives, so it is placed here, though a complete list of the plants of either of the complexes previously discussed would contain it. *Elymus condensatus* likes a moist, sunny, well-drained situation; consequently it is out of the question as a meadow plant and is not of much value under any condition, being coarse and woody. *Delphinium Menziesii* no doubt is poisonous, but its numbers are ordinarily so limited that its interest lies chiefly in the fact that it is a relative of *Delphinium Geyeri*. *Arabis hirsuta* at times acts very much like a weed. One of the three vetches at home here is *Astragalus tenellus*, the only upland vetch in the new-meadow development.

METHOD OF IRRIGATION USED

Before considering the transition itself—that is, the artificial transformation of upland to meadowland—the reader should know something of the mechanical means employed. Although the ranch owners have taken some pains to build large reservoirs, such as the one shown in Plate CI, figure 2, the actual distribution of the water over the land is accomplished in the crudest way imaginable. A ditch is built along what is obviously the highest ridge of a given area and provided with the

customary boxes where they seem to be needed. Very few laterals are used, and there is no secondary ditching. The ditch is opened at intervals and the water allowed to creep out over the land. Naturally it follows the path of least resistance. In order that it may reach some of the high places as well as all of the low, temporary ridges of earth are thrown up, which may perhaps be termed "dikelets," since they are too small and unstable to be called "dikes," but which serve the same purpose. Although, of course, this is irrigation in a broad sense, "controlled flooding" would be a term both more accurate and more appropriate for a method in which science plays so small a part. The remarkable thing about this is that the area so treated really receives a very even soaking; and if there are a few higher places that are not as wet as the land as a whole, so there are higher places in the natural meadow that are always relatively dry. After all, then, controlled flooding furnishes conditions almost analogous to those present in the natural meadow, an important point which, once attained, makes it possible to realize that these uplands, geologically the same as the valley they inclose, potentially are capable of the same vegetative results.

THE TRANSITION

The first interest in this transition may be expressed by the question, "What happens to the upland plants?" The great bulk of them perish very soon. However, assuming that the water is turned on in the spring and allowed to remain until the soil is saturated and is thereafter replaced at intervals frequently enough to keep the ground wet (the common procedure), many of the plants may reach maturity. These readily fall into two classes: First, those of little economic value, either because of actual numerical or structural deficiency or because of lack of ability to cope successfully with the new conditions; and, second, those which flourish under the new conditions and often possess great economic value. The following represent the first class:

UPLAND PLANTS OF SOME IMPORTANCE FIRST SEASON IRRIGATED

Oryzopis hymenoides (R. and S.) Ricker.	*Pentstemon exilifolius* A. Nels.
Stipa comata Trin. and Rupr.	*Chrysothamnus frigidus* Greene.
Potentilla pennsylvanica L., var. *strigosa* Pursh.	*Gaillardia aristata* Pursh.
Astragalus tenellus Pursh.	*Solidago concinna* A. Nels.
Lupinus parviflorus Nutt.	*Tetradymia inermis* Nutt.

I have already spoken of the limitations of Indian millet. Not infrequently though, an area of upland will contain one to several spots, which with controlled irrigation could be much more profitably used for growing millet than rushes. The rushes are not nearly so nutritious, but, as will be shown later, will monopolize these sandy places under the controlled-

flooding system. With moderate moisture millet becomes even prolific and attains a height of about 60 cm.

Stipa comata is a good pasture grass, but the long awns may be fatal to stock because of the presence of tiny barbs. On the range the animals seek it either before the awns have developed or after they have fallen. Altogether, it is fortunate that it is able to survive only one season of meadow conditions.

The next plant that needs more than mention is vetch, the only one persisting of the 10 upland kinds listed. Its ability to persist makes it the connecting link between the upland vetches and those of the lowland which are to invade the developing meadow.

The lupins (Pl. C, fig. 2; CII, fig. 1), which persist a summer under controlled flooding, could probably be perpetuated indefinitely under controlled irrigation. However, since some species are strongly suspected of being poisonous to stock, at least during certain periods of their growth, their cultivation can not be advised, unless careful means are taken to ascertain this fact as regards the local species. These are numerous, and some are known to be not only harmless but of great value. Such is the case with an Idaho species which I have seen form, with the farmer's encouragement, a nearly pure stand on rather sandy bottom lands. This was cut just before the pods became dry, and when fed mixed with hay, both cattle and horses relished and thrived on it during the winter.

The next list represents the chief contribution of the upland flora to the growing meadow formation.

UPLAND PLANTS TENDING TO DOMINANCE THE FIRST SEASON IRRIGATED

Agropyron albicans R. and S.	*Carex siccata* Dewey.
Agropyron dasystachyum (Hook) Scribn.	*Carex stenophylla* Wahl.
Agropyron molle Rydb.	*Arabis hirsuta* Scop.
Bouteloua oligostachya (Nutt.) Torr.	*Antennaria parvifolia* Nutt.
Koeleria cristata (L.) Pers.	*Grindelia subalpina* Greene.

Nearly a dozen upland plants not only persist under controlled flooding but even flourish, at least when they happen to be established on a relatively high spot. With the advent of the first meadow plants (some of which are next listed) two opposing elements must be considered, one of which has had to adapt itself to an environment partially new.

MEADOW PLANTS APPEARING ON UPLAND THE FIRST SEASON IRRIGATED

Hordeum jubatum L.	*Astragalus hypoglottis* L.
Sporobolus brevifolius (Nutt.) Scribn.	*Oxytropis deflexus* DC.
Juncus longistylis Torr.	*Plantago eriopoda* Torr.
Astragalus Bodinii Sheld.	

By the end of the first summer these typically meadow plants are almost certain to be represented, sometimes only by scattered individ-

uals, again completely appropriating areas left barren because of the death of upland plants that were unable to grow in the new environment.

These two elements furnish the foundation for two distinct lines of development which the upland may undergo in its transformation. The value of the respective components may be noted profitably now.

Agropyron Smithii, strangely enough, seems to be the only species that develops either vigorously or abundantly. There are at least two possible reasons for this. Attention has already been called to the fact that it prefers the slopes where the moisture content is greater and more uniform, so it may be the only species that is capable of using to advantage the increase in available moisture. Or it is not impossible that some of the other kinds, under the new conditions, become indistinguishable from the true *A. Smithii*, with which they not infrequently grow and from which they are separated by such characters as pubescent glumes and comparative awn development, characters which there is good reason to believe are easily modified by environmental factors.

Koeleria cristata and *Bouteloua oligostachya* and the two sedges noted are valuable, but the controlled-flooding method of irrigation caused their almost total disappearance by the second season.

Arabis hirsuta develops best, as will be evident when controlled irrigation is used, becoming one of the few native weeds.

Antennaria parvifolia is an everlasting nuisance on comparatively dry places. Plate CII, figure 1, shows its excessive development along a meadow edge. It readily succumbs to too much water, but unhappily the regular order of succession seems to mean that it will usually be replaced by *Pedicularis crenulata*, the weed that so frequently ruins meadows.

Grindelia subalpina reaches its greatest development the second season, as a weed.

Hordeum jubatum is not necessarily a meadow weed by any means, but since it occurs as such in this region it is included in this list of meadow plants. It is sometimes fed, but is dangerous because of the barbed awns. Like wheat-grass, interest in it has just begun.

Sporobolus brevifolius and *Plantago eriopoda* are of saline or subsaline habitat, and therefore their presence is significant. When an alkaline place appears, the invasion of this valuable [1] grass is the best thing that can happen; if it succeeds in establishing itself, it uses a spot that would be occupied by the plantain or later by one or both species of Sagittaria. (See "Minor plants," pp. 757–758.)

Juncus longistylis is destined to play an important part in the meadow development. Its nutritive value is rightly regarded as good, but it suffers by comparison of its analysis with that of wheat-grass.

[1] Knight, H. G., Hepner, F. E., and Nelson, Aven. Op. cit.

It is not surprising to find these meadow vetches appearing so early when the numerous upland species are recalled, a proof of the upland and lowland similarity as regards the soil and a further index to its character as pointed out in a preceding paragraph. *Astragalus bodinii* develops long, spreading stems which make it difficult to harvest, but its high nutritive value and the evident relish with which it is eaten overcome this drawback. Though its development may be arrested, it will ultimately form a large part of the hay crop.

The other species, *A. hypoglottis*, does not seem able to hold its own long where *A. Bodinii* is present, and the latter will eventually largely replace it.

Oxytropis deflexus belongs to a different habitat and is to be regarded here as a stray. It may be poisonous, but it rarely occurs in any abundance.

Such, then, is the condition of vegetation at the end of the first season. During the second season one of two possible lines of development become definitely established. Either the forming meadow enters upon what may be called the Agropyron phase or else the Hordeum phase. As to which phase appears depends on the following condition: It was observed that the ranch company sometimes ran short of water; and in such a case the newer areas were kept only moist, not wet like those regions longer established, for which the greater part of the available water was conserved. Granted that one or more of the wheat-grasses happened to be dominant over a given area the year before (as was very likely the case) a practically pure stand of this grass was the result (Pl. CV). The presence of an occasional tuft of *Hordeum jubatum* should be noted.

Before tracing through the development of this phase, the other possibility should be mentioned. As a curtailed water supply was essential to the dominance of *Agropyron* spp. at this time, so an abundance produced the Hordeum phase (Pl. CIII, figure 1). This phase is more strongly defined than the other because *Hordeum jubatum* is always the dominant plant. Its chief competitor is *Grindelia subalpina*, which is just as worthless and just as truly a weed.

Here is striking evidence of the aggressive character of a plant which because of its uselessness we call a "weed" and of the unobtrusive character of an indigenous and valuable grass. That is, the development of the Agropyron association is primarily dependent on its local dominance the preceding year. When such is not the case, the artificial condition described above tends to produce a mixed association characterized by one or all of those plants which largely composed the upland and the meadow elements, as discussed previously. Chief among these will be *Bouteloua oligostachya* and *Koeleria cristata*, the two sedges *Carex siccata* and *C. stenophylla*, *Antennaria parvifolia*, the meadow vetches

Astragalus Bondinii and *A. hypoglottis*, and *Juncus longistylus*. *Grindelia subalpina* and *Hordeum jubatum* are usually present in varying abundance but never attain dominance. This development should be contrasted with that of the Hordeum association. Here we have dependence only on the water factor whereas the Hordeum association was dependent not only on this but also primarily on its own dominance the preceding year. In the case of an abundant water supply, whether or not *Hordeum jubatum* was locally present, let alone dominant, the first season, it attained dominance the second. Attention has also been called to the stray plants of *H. jubatum* appearing either in the pure or mixed types of the Agropyron association, a further indication of its aggressiveness.

In the outline of the meadow activities during the second season no mention has been made of possible new emigrants from the lowlands. As some are destined to have a most important share in the further history of the evolutive upland, the following list is given:

MEADOW PLANTS APPEARING ON UPLAND SECOND SEASON IRRIGATED

Deschampsia caespitosa (L.) Beauv.	*Glaux maritima* L.
Juncus balticus Willd. var.	*Orthocarpus luteus* Nutt.
Juncus bufonius L.	*Veronica peregrina* L.
Rumex mexicanus Meisn.	*Gnaphalium palustre* Nutt.
Epilobium Drummondii Haussk.	*Rudbeckia hirta* L.

Deschampsia caespitosa is one of the best meadow grasses. It is frequently associated with *Calamagrostis canadensis* (Michx.) Beauv., which, strangely enough, seemed to be completely absent in the Rock River territory. It is highly probable, however, that it would bear the same relation as *D. caespitosa* toward the various factors involved in the present problem. It is highly nutritious,[1] material collected at this altitude containing 7.76 per cent of crude protein (water-free).

Juncus balticus ranks with *J. longistylus* in forage value. *J. bufonius* is a low diffuse annual.

Rumex mexicanus is always scattering in its distribution, but is usually a perceptible element in natural-meadow hay. It is probably to be regarded as a weed; it is coarse and certainly hard on sickle blades.

The rest are harmless herbs. *Orthocarpus luteus* under some conditions may become quite weedy in character. *Glaux maritima* furnishes by its presence another evidence of saline soil. It is as worthless for food as *Plantago eriopoda*.

A careful examination of either of the associations defined above would show the presence of at least some of these plants. They would be scattered through the dominant species in an entirely inconspicuous manner. In a large way the Agropyron phase would contain a suggestion of *Deschampsia caespitosa*, *Juncus longistylus*, and *Orthocarpus luteus*,

[1] Knight, H. G., Hepner, F. E., and Nelson, Aven. Op. cit.

and other herbs, and the Hordeum phase, *J. balticus*, *Rumex mexicanus*, *Grindelia subalpina*, and others mentioned. However, this does not mean that *D. caespitosa*, for instance, would be absent from the latter phase, but merely that it would occur more frequently in the former; and so with *J. balticus*, which would be less abundant, though not necessarily lacking, in the Agropyron association, and so on.

Before the end of the second growing season seeds of the following meadow plants will have germinated and taken root in the upland, so that by the middle of the next (the third) summer, they will have become a factor to be reckoned with. Therefore their consideration at this time is not out of place.

MEADOW PLANTS APPEARING ON UPLAND THIRD SEASON IRRIGATED

Carex nebraskensis Dewey.	*Carex marcida* Boott.
Carex Gayana Desv.	*Gratiola virginiana* L.
Carex lanuginosa Michx.	*Agoseris glauca* (Pursh) Steud.

Carex nebraskensis is one of the commonest and most valuable[1] of our sedges. It grows in clumps and reaches a good height. It is very similar to *C. variabilis*, which is perhaps even more frequent.

Carex Gayana is often the principal species of a given area. It is much less robust than the other sedges and does not grow as tall. Another drawback is that it has a tendency to mature early and turn yellow, losing much in substance before harvest. *C. lanuginosa*, next to *C. nebraskensis*, is probably the most important of the sedges. It is highly nutritious,[1] and its long narrow leaves and slender stems make it quite grasslike.

The remaining species are mainly of interest because of their comparatively early appearance. They belong to that large series of meadow plants which are present here, absent there, and are usually late in coming in. A large proportion of the swamp species belong to this type (p. 753). By the end of the second summer, then, there has been a considerable invasion of meadow plants.

Plate CIII, figure 2, clearly shows what happens during the third season. The reader will recall the presence of rush in the second-year condition of the Agropyron association. Here it is rapidly replacing the wheatgrass (stunted by too much water) and in the fall this phase were better called the Juncus-Carex, or rush-sedge phase. The next summer (the fourth) it will ordinarily reach its highest development. "Ordinarily," because this step in the program is no doubt dependent on the resumption of the usual controlled flooding, a method which, it will be remembered, was temporarily forsaken because of insufficient water. During my observation this resumption always took place, because by this time the upland had reached the stage where a hay crop was assured and good treatment justifiable. Owing to the relatively dry conditions, *J. longi-*

[1] Knight, H. G., Hepner, F. E., and Nelson, Aven. Op. cit.

stylus was the more abundant rush rather than *J. balticus*, which likes the wetter areas; similarly *Carex Gayana* and *C. marcida* outranked *C. nebraskensis*. *C. lanuginosa* was not present. The hay made from this association for the fourth season showed a marked increase in the percentage of *Deschampsia caespitosa*.

In the Hordeum phase the evolution is somewhat different and often less rapid than in the rush-sedge phase. Controlled flooding, the factor which, by drowning all competition, made possible the dominance of *Hordeum jubatum*, the next year weakened this same dominance. *Juncus balticus*, and even *Deschampsia caespitosa*, are much better suited to prolonged wettings. The result was that by the fourth season, the rush-sedge phase had been evolved here also, but with less definiteness unless complete destruction of the virulent weed, *H. jubatum*, was hastened in a novel and unexpected way. In some cases this annihilation was actually accomplished by the sudden appearance of the smut, *Ustilago hordei* (Pers.) Kell. Acres of the grass were often affected, it being practically impossible to find a single plant which did not have all or nearly all of its heads completely smutted. The coming of the new enemy, coupled with the already serious crowding of plants better suited to the wet conditions, could result in only one thing. The rush-sedge supplanted the Hordeum phase, just as the latter had supplanted the Agropyron phase, except that in this case its components were other species. The rush was *J. balticus*, the sedges were *Carex nebraskensis* and *C. lanuginosa*, and the proportion of *D. caespitosa* was often much greater. When the smut did not appear, at least another year was necessary for the drowning out of *H. jubatum*.

Thus, by the fourth year, or at least by the fifth, the upland normally reached the condition we have called the "rush-sedge phase", a condition characterized by the presence of plants belonging in large part to the rush or sedge groups or families. This phase is more stable than either of the earlier stages (the Agropyron or Hordeum); but it, too, soon changes.

The growing abundance of *Deschampsia caespitosa* has been mentioned; in fact, in some cases it came on so rapidly that it became established at the same time as the Juncus-Carex phase forming what might be called the Juncus-Carex-Deschampsia phase. This was particularly likely to be the case when the upland passed through the Hordeum stage At any rate, a year or two usually showed the condition illustrated in Plate CIV, figure 1. This appears to be a nearly pure stand of *D. caespitosa*; but in reality it contains a small percentage of rush, principally *J. balticus*, if its origin has been by way of the Hordeum phase, or of *J. longistylus* and sedge, if its development has been through the Agropyron phase.

At this time there is a tendency of certain plants to attain local dominance. Naturally among these are *Carex Gayana*, *C. nebraskensis*, and

Astragalus Bodinii. The species of Carex have a high water requirement and belong to the cycle resulting from the continuous use from the first of controlled flooding. The best development of the vetch was coincident to the Agropyron phase; otherwise its growth was limited to isolated, often more gravelly, elevated places of relative dryness. The exact conditions that produce these subphases, as they may be called, are not understood and represent only one of the many points which have yet to be fully worked out.

The Deschampsia phase is by far the most stable yet considered. Once established, controlled flooding seemed to satisfy its water requirement so exactly that its character fluctuated but little from year to year. The areas longest under water, however, gave evidence of two possible further changes; either a gradual increase in the abundance of rush (largely *Juncus balticus*) or a gradual increase in the number of kinds of plants. The former case meant the ushering in of the *Juncus balticus*, or wire-grass, phase the presence of which typifies swamp conditions and is the forerunner of the bog. Besides wire-grass, the hay harvest from this phase at Rock Creek contained some at least of the following plants:

SWAMP SPECIES TENDING TO INVADE WETTER PARTS OF MEADOW

Calamagrostis hyperborea Lange.	*Habenaria viridiflora* Cham.
Glyceria borealis (Nash) A. Nels.	*Rumex occidentalis* Wats.
Eleocharis palustris (L.) R. and S.	*Ranunculus reptans* L.
Scirpus microcarpus Presl.	

Of these plants only two are ordinarily of sufficient importance to deserve comment. *Eleocharis palustris*, naturally an inhabitant of pond margins, finds in the wire-grass phase an environment to which it is well suited and it soon becomes an important factor. Its value as forage is fully as great as that of the rushes.[1] *Scripus microcarpus*, like the preceding, is indicative of marshy conditions. It is scattering in its distribution, but its presence is to be noted with satisfaction, as it is one of the few members of this phase that possess a considerable forage value.[1]

The other possibility, the gradual increase in the number of different species, is yet to be considered. This change is even slower than the other. For one thing, there is now a firmly established turf in which any plant finds it difficult to secure a foothold. Finally, however, now here, now there, some local variation in conditions or some factor which escapes our notice permits the invasion of many species, such as those listed under the heading "Meadow plants appearing at some later season" (p. 758). Only three of these are noteworthy: *Cicuta occidentalis* is a poisonous parsnip which for its best development needs the conditions that produce the wire-grass phase. *Pedicularis crenulata* is no doubt the worst weed of the natural meadows, but strangely enough does not seem to bother the made meadows until late. If it appears, the *Carex Gayana*

[1] Knight, H. G., Hepner, F. E., and Nelson, Aven. Op. cit.

subphase seems to be its most likely point of attack. *Carduus foliosus* is sometimes very troublesome. Fortunately it, too, is mostly confined to the natural meadow.

Gradually, then, the upland takes on the cosmopolitan character of the natural meadowland shown in Plate CIV, figure 2. In other words, those finer adjustments that involve plants which possess keener sensibility to moisture content and to slight soil variations are brought about by nature only after many years until finally there exists that marvelous complex of species growing in perfect equilibrium which is known as the natural meadow.

ECONOMIC APPLICATION OF OBSERVATIONS

Such, then, is the story of the artificial production of a natural meadowland. One distinct type of vegetation completely supplanted another type of vegetation. This change was relatively gradual and not abrupt; it was readily divisible into periods, each period or stage being characterized by certain species which dominated that period, only to be recessive in the next; and lastly, the forage values of the various plants have been given.

These observations have proved that it is possible to control the physical stages of the evolutive upland. Therefore, if stockmen desire to augment their yield of natural hay, their procedure should be as follows:

First, a careful study of the upland area to be transformed should be made. It was shown that in the case of the Rock Creek project the upland and lowland were of the same geological formation and the soils of essentially the same character. Presumably this is important, but no study has been made of dissimilar regions. The principal plants should be noted, and if the area were large those parts which supported a good stand of wheat-grass or lupin (see above) or Indian millet should be mapped out, because on this knowledge would depend an intelligent use of the available water.

Second, a surveyed and modern system of irrigation should be established for use on the tract, so that not only controlled flooding but also controlled irrigation could be employed as occasion demanded. The latter method is essential for the development of the Agropyron phase, which was eliminated at Rock River, unless by chance the water supply was curtailed and conditions produced simulating those made possible by controlled irrigation. Briggs and Shantz[1] have shown that *Agropyron Smithii* has a water requirement of 1,076 units for every unit of dry weight produced, as compared with alfalfa with 831. With facilities for controlled irrigation the farmer should be able to furnish with a little practice the amount of water required to develop to the fullest the

[1] Briggs, L. J., and Shantz, H. L. Relative water requirement of plants. *In* Jour. Agr. Research, v. 3, no. 1, p. 1-63, pl. 1-7. 1914. Literature cited, p. 62-63.

latent possibilities of this native grain. The advisability of the preservation of this phase from year to year is a little doubtful. It might be successful, but it would probably never give the yield to the acre that the Deschampsia phase furnishes and is less nutritious, unless the later phase contains a large percentage of *Juncus balticus*. Besides, it is not improbable that after a year or two *Hordeum jubatum* would be able to maintain itself in such abundance that it would ruin the wheat-grass crop (Pl. CII, fig. 2). Then, too, controlled irrigation is more expensive than controlled flooding, so that the question of practicability enters. Altogether, the evidence seems to indicate that, whenever possible, the Agropyron phase should be encouraged for a year, or possibly two, in order to eliminate the Hordeum phase (the constant result of controlled flooding) and then should be allowed to pass into the Juncus-Carex or Juncus-Carex-Deschampsia phase, according to the natural tendency.

In starting the transformation all precautions should be taken to eliminate the worthless Hordeum phase, a stage which, once established, means from one to several seasons lost, with no advantage to the farmer. In case wheat-grass was not present on the upland, controlled irrigation tended to the development of a mixed association.

Considering the additional expense, it is thought probable that in most cases the Hordeum phase had better be tolerated, as the transition may be more rapid to the Deschampsia phase.

The rush-sedge phase (the next, the reader will recall, in the cycle of normal succession) should not be encouraged. It is doubtful whether there is any escaping its presence, although a uniform and constant water supply is probably the chief factor that tends to modify it into the Juncus-Carex-Deschampsia phase. Care must be taken, lest with too much water it revert to *Juncus balticus*. Whether evolved from the Agropyron or the Hordeum phase, none of its chief components possess the nutritive value of *Deschampsia caespitosa*. *Carex lanuginosa* ranks the highest, but it is likely to form a subphase of its own.

The two principal species of the Deschampsia phase represent extremes in forage value. *D. caespitosa* is one of the most nutritious meadow plants[1] and *Juncus balticus* is one of the least nutritious. Hence, the importance of maintaining *D. caespitosa* as the dominant plant of this phase. This accomplished, the farmer has the best natural meadow the region affords, which will average 1½ tons to the acre and will remain for years free from meadow weeds.

If too much water is used, this phase becomes replaced by *Juncus balticus*. The only species in this phase that in any way makes up for the loss of *Deschampsia caespitosa* is *Scirpus microcarpus*. If the farmer allows the Juncus phase to enter, he should consider that his meadow has reverted. The next step is the bog, which would mean the destruc-

[1] Knight, H. G., Hepner, F. E., and Nelson, Aven. Op. cit.

tion of the meadow. However, nature works just the other way. Aquatic plants tend to fill up the bogs (see p. 758); then come the species of the *J. balticus* phase. Besides being so much less nutritious than the *D. caespitosa*, the hay of this phase will not average a ton to the acre; often only half a ton.

Now compare the man-made natural meadow with the nature-made natural meadow. If the highest type of the former, the Deschampsia stage, be taken as the standard, it far excels the natural condition. This is because the latter is usually that mixed type to which the Deschampsia phase tends, perhaps always ultimately reaches. *Deschampsia caespitosa* may be the most conspicuous plant in a natural meadow, but it rarely, if ever, is truly dominant over any considerable area. It is more likely to contain plants which are either useless or actually harmful and must be regarded as meadow weeds. The yield of the natural meadow is seldom as high to the acre as that of the Deschampsia phase of the artificial. On the other hand, the rush-sedge and *Juncus balticus* phases often have their counterparts in the natural meadow, so that by producing these the farmer gains nothing more than an increased acreage. So long as the Deschampsia phase can be maintained, not only a greater quantity but also a better quality of natural meadow hay has been obtained.

MEADOW HAY VERSUS ALFALFA AND GRAIN

In the spring of 1914 two tracts on the upland of this ranch, which so largely had been converted to meadow, were sown, one to alfalfa and the other to oats. The land was improperly prepared, and the distribution of water was uneven and poorly regulated. In spite of these obvious drawbacks, the two fields had produced by the end of the season the crops shown in Plate CV. It had been impossible to obtain definite data from the foreman of the ranch, but the yield of oats probably reached 30 bushels to the acre. Considering the way in which they were grown, this is a good yield. The illustration shows the excellent stand of alfalfa. A field on a neighboring ranch which was partly dry-farmed, there being water only during the fore part of the season, produced between 3 and 4 tons of alfalfa to the acre. If we recall the large number of native legumes the upland supported, we will not be surprised at the success of this legume, a plant notoriously fond of sweet soils rich in lime.

Plate CV, figure 1, shows the upland as it usually looks the first season under water, the strong development of *Antennaria parvifolia* being noteworthy. It is here that *Arabis hirsuta* flourished and became weedlike.

It must not be concluded that the artificial raising of natural hay does not pay. There are factors to be reckoned with which have not yet been considered. In the first place, it must be remembered that a natural meadow, once established, is fixed so long as the water supply holds out. On the other hand, alfalfa at this altitude needs reseeding every few

years, and oats often fail to mature. Besides, grain can not be grown indefinitely on the same land, even virgin land, without rotation. In the second place, the expenses of growing the cultivated crops are far greater than those of growing the uncultivated. The farmer who grows a natural meadow even by controlled irrigation as outlined above, ultimately will have less expense than the farmer who grows grain or alfalfa and continually has to repair ditches and regulate the water supply. Besides, he has not only been saved the initial cost of buying seed and of preparing a seed bed but he has also been able to utilize his entire upland, for all of it is potentially a meadowland.

These conclusions apply only to farming under the climatic conditions that exist at Rock Creek. At lower altitudes, where conditions are less rigorous and where cultivated crops well suited to the region have been long grown, this method of raising hay can not be too strongly condemned. It could be used with success only where hundreds of acres were available.

Even at Rock Creek on a smaller scale it would mean a criminal waste of land and water, as the ranch company is even now drawing so heavily on its reservoirs and on Rock Creek that during a dry season some of its meadows suffer. The owners have about reached the limit of increasing their hay yield by the growth of more natural meadows. Alfalfa gave much greater yields than the natural vegetation, and Briggs and Shantz have shown that alfalfa has a water requirement of only 831 units for every unit of dry weight produced. Further augmentation can come only by the raising of crops that require less water and give greater yields to the acre in return. The recent perfecting of grains and hays adapted to the high altitude and short season of the Laramie Plains will soon make this method of farming infeasible even under such conditions as those of Rock Creek.

MINOR PLANTS

Below are lists of those plants occurring in the Rock Creek region which have not been mentioned in the body of this paper, being mostly of interest to botanists only.

BENCH LAND

Allium cernuum Roth.
Allium textile Nels. and Macbr.
Eriogonum ovalifolium Nutt.
Eriogonum flavum Nutt.
Paronychia sessilifolia Nutt., var. *brevicuspis* A. Nels.
Lesquerella condensata A. Nels.
Lesquerella montana (Gray) Wats.
Astragalus Drummondii Dougl.
Astragalus missouriensis Nutt.
Astragalus nitidus Dougl.
Astragalus Purshii Dougl.
Astragalus Shortianus Nutt.
Euphorbia montana Engelm.
Opuntia polyacantha Haw.
Cogswellia orientalis Jones.
Gilia pungens (Torr.) Benth.
Gilia spicata Nutt.
Phlox glabrata (E. Nels.) Brand.
Oreocarya flavoculata A. Nels.
Oreocarya thyrsiflora Greene.
Chrysopsis villosa Nutt.
Erigeron Eatonii Gray.
Sideranthus grindelioides (Nutt.) Britton.
Stenotus acaulis Nutt.

DRAWS

Calochortus Gunnisonii Wats.
Calochortus Watsonii Jones.
Eriogonum umbellatum Torr., var. *intectum* A. Nels.
Eriogonum campanulatum Nutt.
Arenaria congesta Nutt.
Astragalus pectinatus Dougl.
Astragalus succulentus Rich.
Viola Nuttallii Pursh.
Lithospermum angustifolium Michx.
Mertensia brevistyla Wats.
Senecio perplexus A. Nels.

BENCH SLOPE

Comandra pallida A. DC.
Fragaria ovalis (Lehm.) Rydb., var. *glauca* (Wats.) A. Nels.
Astragalus bisulcatus (Hook.) Gray.
Astragalus carolinianus L.
Thermopsis arenosa A. Nels.
Epilobium paniculatum Nutt.
Gilia pharnaceoides Benth.
Pentstemon alpinus Torr.
Castilleja linariaefolia Benth.
Pentstemon strictus Benth.
Achillea millefolium L.
Helianthus Nuttallii T. and G.
Lygodesmia grandiflora T. and G.
Amelanchier oreophila A. Nels.
Prunus demissa (Nutt.) Dietr., var. *melanocarpa* A. Nels.
Shepherdia argentea Nutt.
Cornus stolonifera Michx.

STREAM VALLEY

Salix Bebbiana Sarg.
Salix caudata Muhl., var. *Watsonii* Bebb.
Salix fluviatilis Nutt.
Salix fluviatilis Nutt., var. *exigua* (Nutt.) Sarg.
Salix Fendleriana Anders.
Populus fortissima Nels. and Macbr.
Betula fontinalis Sarg.
Alnus tenuifolia Nutt.

AQUATIC PLANTS OF THE REGION

Potamogeton perfoliatus L.
Lemna minor L.
Batrachium pantothrix S. F. Gray, var.
Callitriche palustris L.
Utricularia vulgaris L.

WOODLAND SPECIES TENDING TO INVADE ADJACENT MEADOWS

Carex aurea Nutt.
Juncus nevadensis Wats.
Arabis columbiana Macoun.
Cardamine Breweri Wats.
Oxytropis Lambertii Pursh.
Geranium Richardsonii F. and M.
Gentiana acuta, var. *strictiflora* Rydb.
Gentiana affinis Griseb.
Castilleja sulphurea Rydb.
Galium boreale L.
Campanula rotundifolia L.
Erigeron asper Nutt.
Senecio crocatus Rydb.

MEADOW PLANTS APPEARING AT SOME LATER SEASON

Equisetum hiemale L.
Triglochin maritima L.
Triglochin palustris L.
Alopecurus fulvus Smith.
Beckmannia erucaeformis (L.) Host.
Carex Douglasii Boott.
Carex valticola Dewey.
Juncus tenuis Willd.
Allium Nuttallii Wats.
Iris missouriensis Nutt.
Sisyrinchium idahoense Bickn.
Habenaria borealis Cham.
Erysimum cheiranthoides L.
Parnassia parviflora DC.
Argentina anserina (L.) Rydb.
Thermopsis divaricarpa A. Nels.
Vicia linearis (Nutt.) Greene.
Sidalcea neomexicana Gray.
Cicuta occidentalis Greene.
Zizia cordata (Walt.) Koch.
Dodecatheon pauciflorum (Durand) Greene.
Primula farinosa, var. *incana* (Jones) Fernald.
Pedicularis crenulata Benth.
Carduus foliosus Hook.
Crepis runcinata (James) T. and G.

SUMMARY

The artificial formation of natural meadows is a gradual change divisible into several distinct periods or phases, each characterized by one or more particular species.

The relative permanence of these stages may be largely controlled by regulation of the water supply. By the same means any stage, in some measure, may be produced at will.

Agropyron spp. and *Deschampsia caespitosa* furnish the most valuable hay.

The yield of the natural meadowlands is generally smaller and less nutritious than the possible yield of the artificial. The latter meadows, however, tend ultimately to be composed of the same type of vegetation that characterizes the natural meadows; therefore it is important to watch and control their development.

This manner of hay raising is practicable at high altitudes where both land and water are abundant and domestic crops are uncertain. Where conditions are favorable for cultivated crops, the method would be wasteful and should be regarded as unsound farming.

With the growing scarcity of farming land and the development of crops suited to areas usually considered nonarable, the practical artificial formation of natural meadows will become limited to regions of even higher altitude and shorter season than those considered in this paper.

PLATE XCVIII

Rock Creek Valley, near Rock River Station. Photographed by Dr. N. H. Darton, of the United States Geological Survey.

PLATE XCIX

A nearer view of the bench slope; the same tree shown in Plate C, figure 1.

PLATE C

Fig. 1.—Where upland and lowland meet. Notice the bench slope; described on page 745. For list of shrubs see "Minor plants, pages 757–758. The cottonwood tree is *Populus fortissima* Nels. and Macbr.

Fig. 2.—Characteristic draw; the stream valley beyond. Lupin, wheat-grass, white sage, and gaillardia in the foreground.

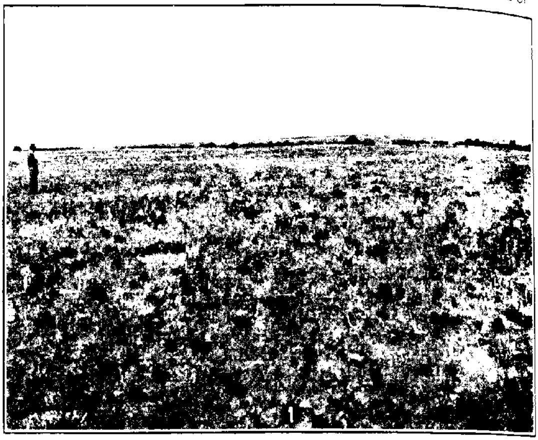


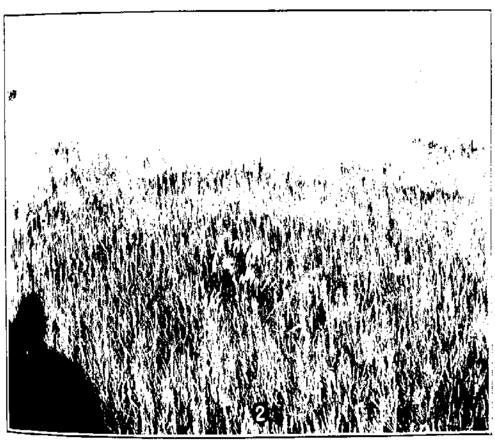
PLATE CI

Fig. 1.—The bench. The course of Rock Creek is indicated by the distant trees.
Fig. 2.—Part of a reservoir on the Rock Creek ranch.

PLATE CII

Fig. 1.—Lupin recessive and cat's-foot becoming dominant. Gay's sedge subphase in background.

Fig. 2.—Wheat-grass phase. Notice the occasional squirrel-tail grass.



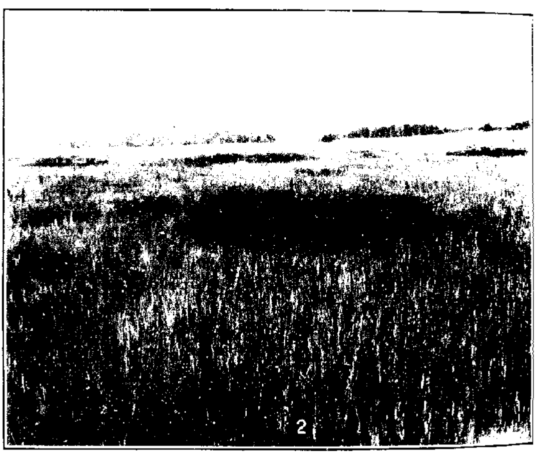


PLATE CIII

Fig. 1.—Squirrel-tail phase. A few grindelias in the foreground.
Fig. 2.—Rush-sedge phase (the darker areas) replacing wheat-grass phase.

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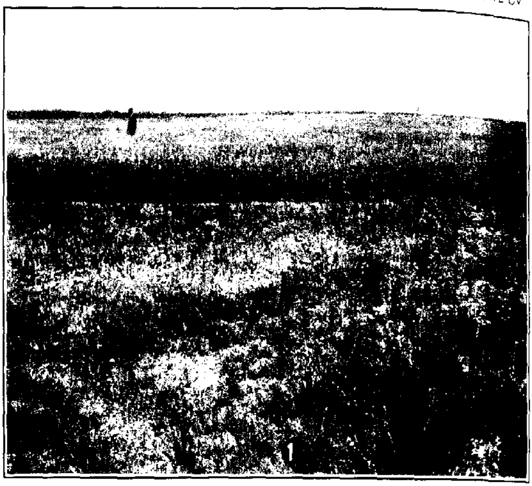
PLATE CIV

Fig. 1.—Hair-grass phase.

Fig. 2.—Natural meadow. Note the cosmopolitan character of vegetation.



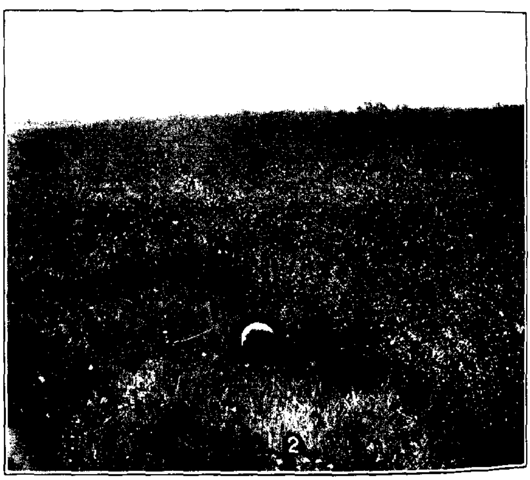


PLATE CV

Fig. 1.—Field of oats on bench. Cat's-foot and other upland plants in foreground.

Fig. 2.—Alfalfa field one year after sowing. Cat's-foot and bench grasses in foreground.